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ABSTRACT

This module enumerates the benefits to be derived from cropping at a waste application site and criteria to be used in selecting a crop for use in a particular situation. Following basic discussions of the requirements of various crops for water, soil-plant-air moisture potentials, crop water tolerance, nutrient removals by various crops, and tolerance to nutrients and salts, practical management techniques are discussed which will extend the usefulness of crop systems in land treatment of wastes. (Author/BB)

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Land Application of Wastes

An Educational Program

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
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Ithaca, New York

CROP SELECTION AND MANAGEMENT ALTERNATIVES

Module 20

January, 1978

SE 025 034

LAND APPLICATION OF WASTES - AN EDUCATIONAL PROGRAM

The objective of this program is to increase the knowledge of engineers, scientists, waste management specialists and other practitioners in the concepts and principles needed to properly utilize the potential of land for the application of wastes. It is designed for individuals concerned with waste disposal alternatives for municipal, industrial, and agricultural wastes. The modules in this Program incorporate knowledge from sanitary and environmental engineering, agronomy, soil science, agricultural engineering, economics, and law.

The program consists of some twenty-five modules and audio-visual materials as appropriate.

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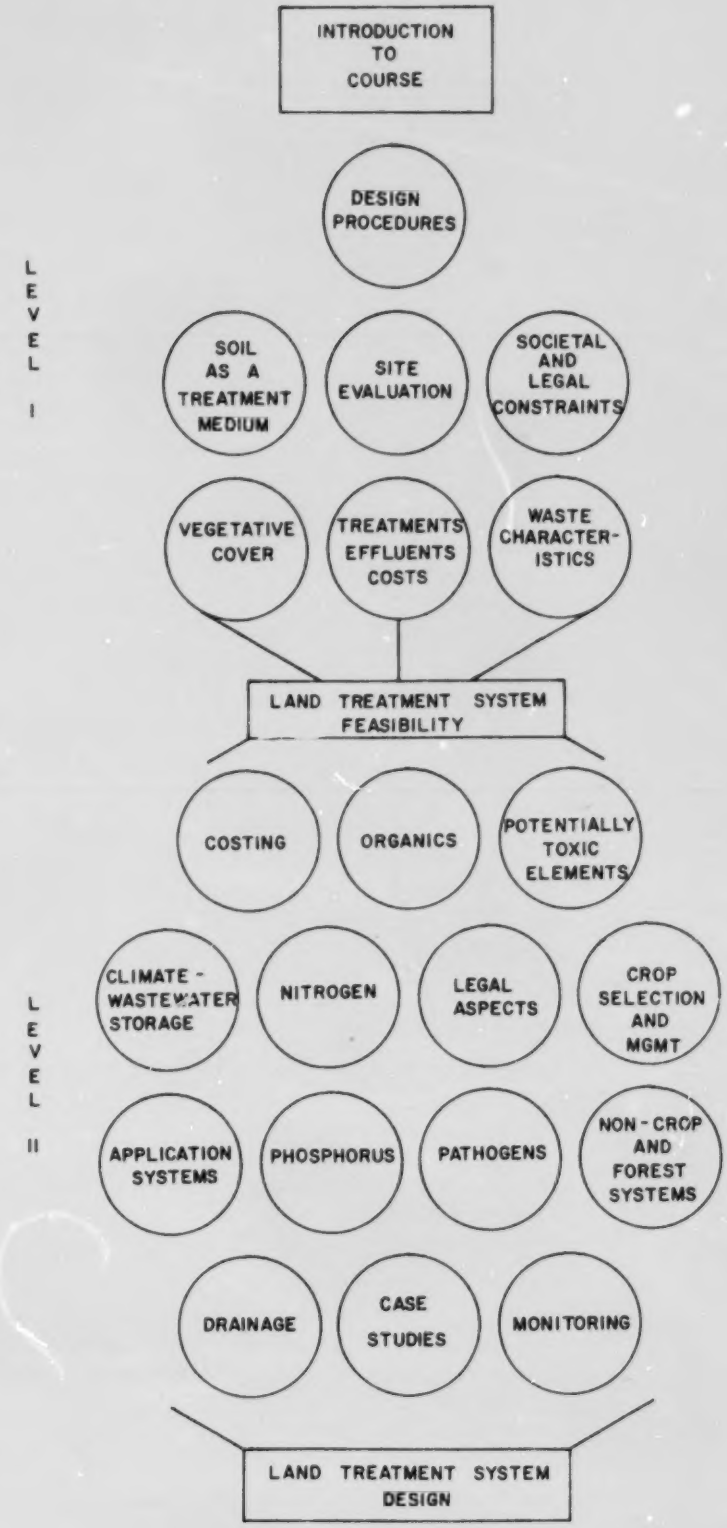

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CROP SELECTION AND MANAGEMENT ALTERNATIVES

Module 20

January, 1978

Summary

This module enumerates the benefits to be derived from cropping at a waste application site and criteria to be used in selecting a crop for use in a particular situation. Following basic discussions of the requirements of various crops for water, soil-plant-air moisture potentials, crop water tolerance, nutrient removals by various crops, and tolerance to nutrients and salts, practical management techniques are discussed which will extend the usefulness of crop systems in land treatment of wastes. This material is included in the section "Practical Considerations".

This is a lengthy module which presents much detailed information on certain crops. Some of this data is in the form of tables, sometimes quite involved. It is not necessary or even desirable for the engineer, planner, and designer (the intended audience of this course) to try to absorb all this information in one reading. Much of the material is intended to create an awareness in the land application site planner of some of the potential benefits and pitfalls of crop selection and management, the value of careful selection of vegetative cover, and the importance of professional advice on questions in this area. The module covers a body of knowledge which probably is not common to most site planners.

Sections I, II and V are probably the most helpful to a person attempting to cover the full range of subject matter in a short time. These sections should be selected by participants in a workshop or short course on land application of wastes.

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Objectives

Upon completion of this module, the participant should be able to:

1. List at least six of the nine criteria for selection of a crop listed in the Introduction.

2. Explain the irrigation water computation given in the example at the end of the section entitled "Evapotranspiration", and use the data given on these pages to duplicate the example for any of the other crops listed.

3. Discuss the major advantages of proper drainage and list at least 8 of the 15 benefits of drainage shown in Table 9.

4. List and discuss several of the most widely used crops at land application sites.

Introduction

The removal of nutrients in harvested crops, higher renovation efficiencies, increased soil stabilization, increased infiltration rate, improved public relations and cost effectiveness are the areas in which cropping may contribute most to the treatment of raw sewage, sewage sludge, and wastewaters. The cost effectiveness of the cropping system will depend upon many things, especially land values, management skills, and cash return from the sale of crops. Crop irrigation has greater land area and management requirements than does a rapid infiltration system. However, sites suited to cropping are generally easier to locate than sites suited to rapid infiltration.

The cost effectiveness of a cropping system depends mainly upon land values, management skills, and cash return from harvested crops.

Farmers and growers try to optimize, within economic constraints, the environment surrounding their crops in order to maximize yields. The primary objectives of a land application project may or may not include maximum crop yield. Maximum economic renovation of wastes is the more direct objective. As stated in Module 3, "Soil as a Treatment Medium", "wastewater is applied at a rate designed to optimize the renovation capacity of the soil/plant medium and to maximize the utilization of the available nutrients within the wastes." Providing less than optimal conditions will result in less than maximum yields and less than maximal nutrient utilization. However, improving drainage and providing irrigation can potentially improve crop yield, crop quality, and nutrient removal in both wet and dry years. This point should be stressed in selling a land application system to a farming community.

The objective of land application is to maximize cost effective renovation. This can, as a by-product, improve agricultural yields.

Sopper (1973) enumerated some of the criteria which should be considered in selecting vegetative cover for a land application site. These included:

(1) water requirement and tolerance

(2) nutrient requirement and tolerance

(3) nutrient utilization and renovation efficiency

(4) sensitivity to potentially toxic elements and salts
(5) insect and disease problems
(6) season of growth and dormancy requirement
(7) natural range
(8) ecosystem stability
(9) demand or market for the product

All of these aspects should receive consideration. Many are interrelated.

As discussed in Module 7, "Vegetative Cover", crop selection is a factor which must be defined before evapotranspiration and percolation (from a given soil, with a given climate) may be estimated with a good degree of accuracy. Before intelligent crop selection can be made, moreover, analyses of the waste to be applied and of the soils involved must be made. Analysis of the crops grown may also be necessary to protect the food chain or monitor site longevity if an unusually high level of any nutrient or potentially toxic element is applied.

Crop selection depends upon waste and soil characteristics. The amount of evapotranspiration and percolation depend upon crop selection.

Analysis of wastewater and sludge should include the tests which have been developed and are routinely made to assess the quality of irrigation waters including electrical conductivity, sodium adsorption ratio (SAR), HCO_3^-, B, and Cl^- (Table 1) as well as the tests usually used to analyze wastewater. Analysis of soils should be made to check pH, levels of toxic elements, and native concentrations of nitrogen and phosphorus (which can affect renovation efficiency). In addition, soil tests should include CEC and all exchangeable cations, especially K, since it is reported to reduce yields when deficient. In arid areas, soil properties which have been correlated with reduced yields are high levels of salts, boron, and sodium.

The wastewater and sludge should be analyzed for electrical conductivity, SAR, HCO_3^-, B, and Cl^- when it is to be used for irrigation. These have all been associated with reduced yields when applied in excess.

Table 1. The constituents usually determined in an irrigation water analysis, their abbreviations, and the units in which they are reported.

Determination	Abbreviation	Unit
Electrical conductivity	EC x 10^6 at 25C	micromhos per cm
Soluble-sodium percentage	SSP	percent
Sodium-adsorption-ratio	SAR	
Boron	B	parts per million, ppm
Dissolved solids	DS	ppm
pH		
Cations:		
Calcium	Ca	Milliequivalents/liter meq/liter
Magnesium	Mg	meq/liter
Sodium	Na	meq/liter
Potassium	K	meq/liter
Sum of cations		meq/liter
Anions:		
Carbonate	CO_3	meq/liter
Bicarbonate	HCO_3	meq/liter
Sulfate	SO_4	meq/liter
Chloride	Cl	meq/liter
Nitrate	NO_3	meq/liter
Sum of anions		meq/liter

Source: Wilcox and Darum, 1967

Crops have been broadly classified (Pound, Crites, and Griffes, 1975) as follows: Perrenials (forage or fruit crops), Annuals (field crops and vegetables), Landscape Vegetation (ornamental trees, shrubs, and turf grasses) and Forests. The latter two "crops" are discussed in a separate module (Module 13, "Non-crop and Forest Systems"). Aquaculture will not be discussed but has been considered a form of cropping (EPA, 1974).

In this module consideration will be directed primarily to highlighting the complexity of tradeoffs which must be made in selecting and managing crops irrigated with wastewater.

Irrigated Crops

Table 2 indicates examples of some of the crops reportedly grown with wastewater irrigation in the U.S.

Table 2. Examples of facilities using land application of wastewater for crop production.

	Population	Flow mgd	(Gal/Cap/Day)	Acres	(In./Acre/Yr)	Crop
Kansas						
Scott City	4,325	0.432	(99.8)	25	(228)	Rice
New Mexico						
Almagordo	25,000	2.5	(100)	260	(130)	Alfalfa, maize, oats, sorghum
Clovis	75,000	3.5	(46)	1,150	(40)	Milo, alfalfa maize, millet, wheat
Raton	2,300	0.5	(217)	200	(33)	Alfalfa
Roswell	40,000	2-3 (2.5)	(62.5)	770	(43)	Alfalfa, barley, maize, cotton
Santa Fe	45,000	5.3	(118)	740	(95)	Alfalfa, apples
Oklahoma						
Duncan	20,000	2.5	(125)	180	(184)	Wheat, bermuda grass
Texas						
Abilene	100,000	9.0	(90)	2,019	(59)	Cotton, maize, bermuda grass
Dumas	9,770	1.0	(102)	585	(22.7)	Wheat, maize
Kingsville	30,000	3.0	(100)	606	(65.7)	Maize
Midland	62,000	4.3	(69)	1,000	(57)	Bermuda grass, alfalfa, milo, cotton
San Angelo	64,000	5.0	(78)	740	(89.7)	Barley, milo, rye, oats, fescue, alfalfa
Uvalde	9,000	0.9	(100)	150	(79.6)	Maize, oats
Dalhart	5,700	0.64	(112)	240	(35)	Hay
Denver City	4,200	0.15	(35.7)	180	(11)	Cotton, grass
Idalou	1,800			40		Feed, cotton
Morton	3,760			50		Cotton
Seagraves	2,500	0.2	(80)	160	(17)	Cotton

Source: Sullivan, Cohn, and Baxter, 1973.

It is evident from Table 2 that for the most part similar crops are irrigated with wastewater as are irrigated with other water. Specific problems have been reported with wastewater irrigation of some crops as discussed below under the category, "Crop Tolerances to Nutrients, Salts, and Potentially Toxic Elements". Table 3, taken from Sullivan, et al., (1973) describes the crops grown outside Medico City. It is evident from this table that practically any crop adapted to the prevailing temperature regime could be grown with wastewater irrigation if the irrigation were applied sparingly so as to meet the crop's water requirements without overloading the soil.

Crop Water Requirements

It is well known that management, climate and plant variety all influence crop yield. Tanner (1974) has recently stressed the importance of water in limiting yield. "(In humid areas) precipitation is sufficient almost always to produce some yield, and yet in most years yield is limited by insufficient water. Much larger yield increases per unit of irrigation are possible in humid regions than in arid regions, which rely almost totally on irrigation." Table 4 presents some yield data from Penn State University. It is evident that application of wastewater substantially increased the yield of most crops in most years. The differences between the 1 in./wk. and 2 in./wk. treatments were not as marked in this particular study. Pound and Crites (1973) state, "A loading of about 4 in./wk. would seem to be the upper limit of a true irrigation system." This is the design rate for seasonal wastewater application to the sandy soils of Muskegon, Michigan.

It is generally agreed that water is limiting, in most of the world, for crop production. Even in humid areas yield is limited by insufficient water in most years.

Table 3. Summary of Agriculture Production 1971-1972. 03 Irrigation District -- Tula Hidalgo, Mexico

Crop	Hectares	Metric Tons
Alfalfa	12,396.40	1,181,376.920
Garlic	94.50	258.456
Peas (large)	12.89	20.820
Green Oats	2,998.75	54,426.714
Squash (small)	674.33	7,282.764
Barley Grain	1,865.43	3,645.410
Barley (forage)		4,059.874
Onion	23.79	168.909
Parsley Seed	3.53	4.589
Cabbage	27.95	501.843
Peas	1.00	7.900
Green Hot Peppers	768.80	8,231.350
Flowers	10.41	
Navy Beans	1,259.02	1,563.870
Am. String Beans	58.30	151.580
Spinach	0.82	9.020
Fruit Trees	25.08	213.180
Sunflower	37.19	230.578
Lima Beans	95.84	1,990.070
Am. Tomato	1,554.65	49,437.870
Lettuce	74.47	1,457.764
Corn (kernels)	17,053.60	70,260.525
Corn (forage)		65,179.023
Corn (sweet)	101.20	7,084.000
Forage Turnips	112.37	1,011.330
Melon	1.00	7.100
Cucumber	34.74	166.752
Meadow Grass	12.80	2,080.000
Tomato	216.90	2,051.706
Wheat Grain	7,293.79	13,865.494
Watermellon	0.40	3.960
	46,809.95	1,476,749.371
	Acres	U.S. Tons
	115,620.65	1,624,424.30

Note: 1 metric ton = 1.1 (U.S.) tons
1 (U.S.) ton = 0.907 metric tons
1 hectare = 2.47 acres

Note: The crop hectares listed are more than the hectares of land available since a second crop in some instances has been produced on the same land.

Source: Sullivan, Cohn, and Baxter, 1973.

Table 4. Crop Yields at Various Levels of Wastewater Application in Penn State University Studies

Crop	Unit	0 in./wk	1 in./wk	2 in./wk
1963				
Wheat	bu/acre	48	45	54
Corn	bu/acre	73	103	105
Alfalfa	tons/acre	2.18	3.73	5.12
Red clover	tons/acre	2.48	4.90	4.59
1964				
Red clover	tons/acre	1.76	5.30	5.12
Corn	bu/acre	81	121	116
Corn stover	tons/acre	3.58	7.29	8.48
Oats	bu/acre	82	124	97
1965				
Alfalfa	tons/acre	2.27	4.67	5.42
Corn	bu/acre	63	114	111
Corn silage	tons/acre	3.11	3.93	4.32
Oats	bu/acre	45	80	73
Reed canary grass	tons/acre	--	--	6.13
1966				
Alfalfa	tons/acre	1.95	3.86	4.38
Corn	bu/acre	18[a] 33[b]	115[a] 98[b]	140[a] 115[b]
Corn silage	tons/acre	2.75[a] 2.47[b]	9.02[a] 4.45[b]	7.53[a] 5.68[b]
Reed canary grass	tons/acre	-- --	-- --	4.32[a] --
1967				
Corn	bu/acre	93[c] 87[d]	96[c] 79[d]	116[c] 80[d]
Corn silage	tons/acre	4.67[c] --	4.47[c] --	4.42[c] --
Reed canary grass	tons/acre	-- --	-- --	7.03[c] --

a. 19-in. row
b. 38-in. row
c. 20-in. row
d. 40-in. row

Source: Pound and Crites, 1973.

In traditional irrigation planning the gross volume of water required at the diversion point is made up of a number of components.

a) crop needs (function of potential evapotranspiration and crop)
b) soil needs (a function of the salinity problem and tillage requirements)
c) transmission and distribution losses (runoff and deep seepage from fields, deep seepage and evaporation from distribution channels, and administrative losses)
d) storage losses (evaporation and seepage from reservoir)

Of all of these elements, crop needs has received the greatest amount of study and may be estimated with a high degree of accuracy.

Crops differ in their rooting habits, and thus soil drainage characteristics can influence their response to irrigation. Figure 1 is reproduced from SCS (1964) and illustrates the rooting habits of many common crops. Spinach has a shallow rooting habit, sugar beet an intermediate and alfalfa a deep rooting habit. Shallow rooted plants thrive with frequent irrigations, though they will not necessarily stand waterlogging. In mixed stands the requirements of the most shallow rooted species (usually clovers) dictates the required frequency of irrigations.

Deep rooted plants take up a similar amount of water as shallow rooted species when moisture is adequate. Deep rooted plants should not be hurt by frequent irrigations if drainage is adequate. Whenever irrigation is practiced, care must be taken to wet the soil profile uniformly at least through the effective rooting depth. Keeping the subsoil too wet or too dry will restrict root depth and increase the degree of drought damage which might occur if for some reason water supplies are interrupted. The effect of wet subsoil

Crops differ in rooting habits. Deep rooted plants take up moisture from a greater depth. They can be harmed, however, by waterlogged subsoil.

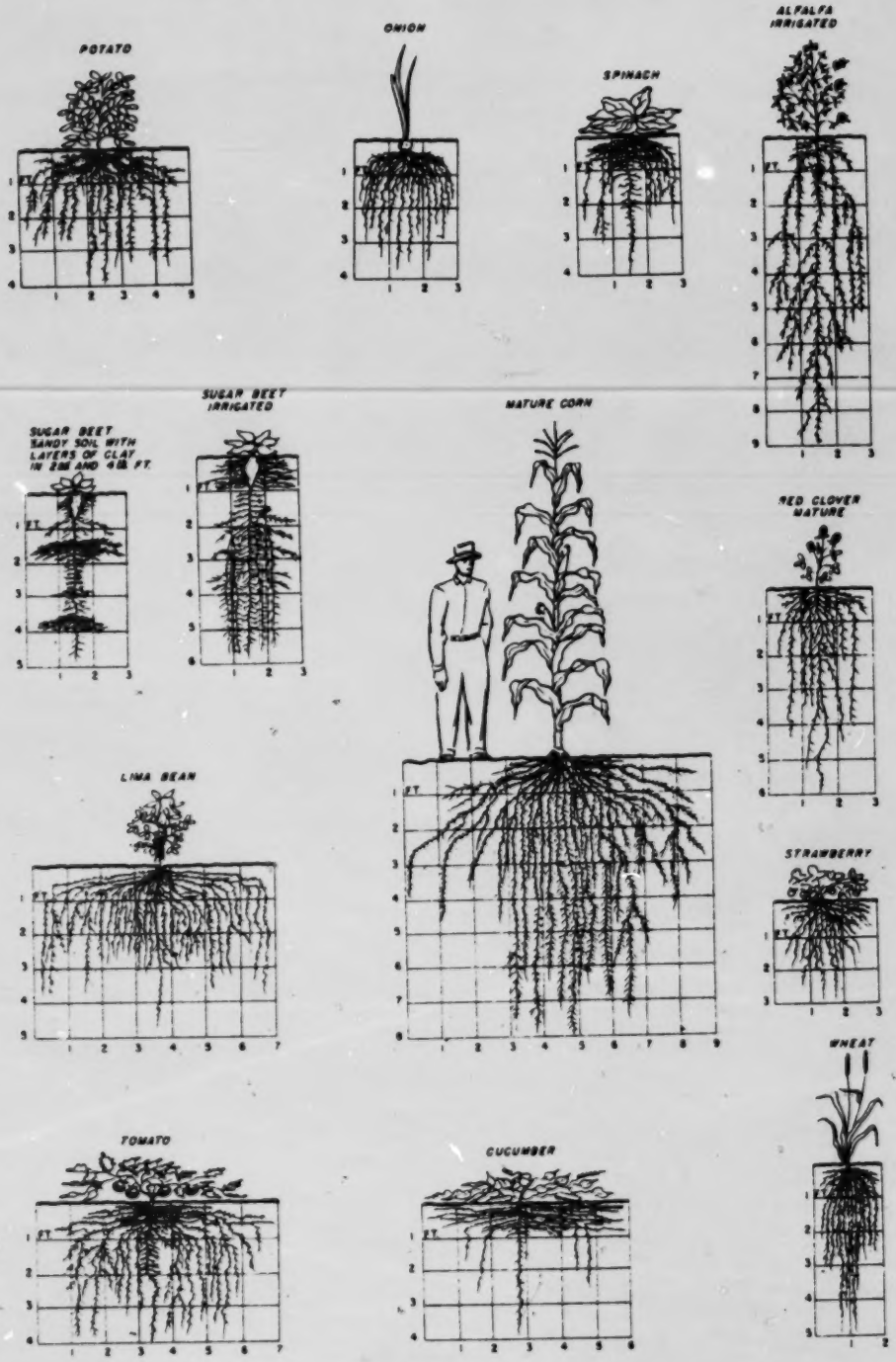

Figure 1 --Root systems of field and vegetable crops in deep irrigated soils of central United States.

Source: SCS (1964).

may not be so great on annual crops which may be considered to be shallow rooted until they approach flowering.

Tanner (1974) has shown that yield has been well correlated with transpiration. Since in the Penn State study (Table 4) yields between the 1 in./wk. and 2 in./wk. treatments were similar, the second inch of the 2 inch treatment applied in addition to natural precipitation was probably lost as percolate rather than as increased evapotranspiration. Figure 2 illustrates "production functions", plots of crop yield versus water application, which are useful to engineers determining irrigation water requirements. Such functions are empirical and must be generated in the area to which they will be applied. (The State Extension Service or agricultural college can provide these curves for locally irrigated crops). From this type of data, culturally and economically optimum amounts of water can be derived. The shape of this curve gives a good indication of the qualitative effects which may be expected from increasing water applications. Maximum yield is associated with maximum transpiration. Maximum transpiration can be approached by providing irrigation that makes up the deficit between precipitation and potential evapotranspiration. Increasing water application after this increases the volume of percolating water. As discussed below, reduced yield with increasing water application could be due to poor aeration adversely affecting root growth and stand (Figure 2). It could also be due to a reduced supply of available nitrogen as a result of leaching losses or the inhibition of mineralization of soil organic nitrogen. The latter response may not be seen if the wastewater contains considerable nitrogen.

Production functions can be generated to indicate optimum irrigation requirements. Water applied above the optimum would be expressed as percolate through the soil.

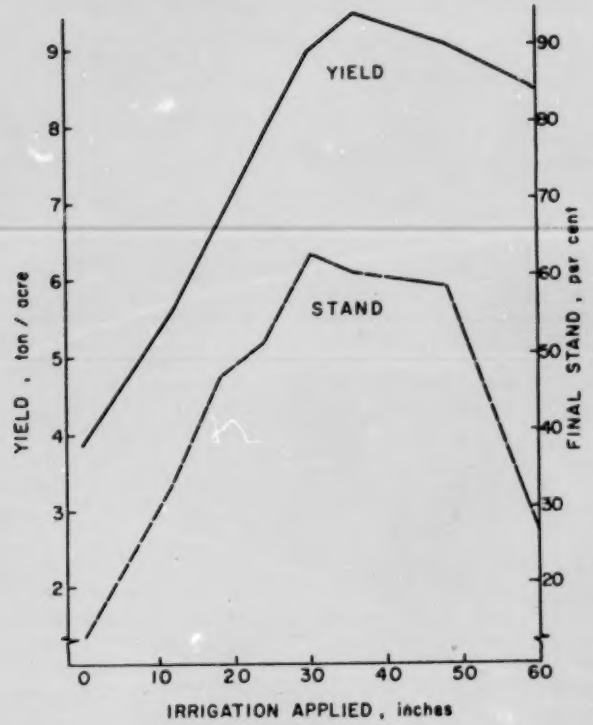

Fig. 2 Six-year average yield, and final stand, of alfalfa at Davis, California, in response to different amounts of annual irrigation. (Perfect stand contained 1.5 plants/ft^2.) (Taken from Beckett and Robertson, 1917.) The growing season is 242 days.

Evapotranspiration

Evaporation from wet surface and transpiration from well irrigated crops is limited by the energy available to evaporate water.

Energy Budget studies have shown:

$$R_N + \ell - E - H - S - PS = 0$$

when R_N = net radiation, ℓ = latent heat of vaporization, E = evapotranspiration, H = sensible heat stored in air, S = sensible heat stored in soil, and PS = photosynthesis. Evapotranspiration from a dense sod is essentially equal to evaporation from a wet surface and is limited by climate, i.e., available energy. The two major sources of energy driving evapotranspiration are net radiation and convection of warm air with less than 100% relative humidity. Conduction of heat from the soil may be an additional source of energy, especially if water is applied to a hot, dry soil. Figure 3 illustrates the nature of the water potential gradient which exists between soils-plant-air. It will be noted that as soil moisture decreases, the potential gradient is lessened to a certain extent (10 to 20 bars) but this does not greatly affect the overall potential. Evapotranspiration is decreased due to decreased capillary flow as the soil surface dries. The degree to which a plant may satisy a high transpiration demand depends primarily upon the size and density of its root system. Anything which restricts the depth or vigor of root penetration may restrict transpiration.

Evapotranspiration is limited by, and driven by, available energy. The sources of available energy are net radiation and convection of warm air.

Transpiration rate depends upon the size and density of the root system. Anything which restricts the depth or vigor of the roots restricts transpiration.

Net radiation is the largest source of energy available for evaporating water. This is true even of advective situations. Net radiation is defined as:

$$R_N = (1-a)\ R_G + R_{NT}$$

where R_N = net radiation, R_G = solar (global) radiation, R_{NT} = net thermal radiation, and a = albedo or reflectance of solar radiation (a function of crop and soil cover).

TYPICAL SOIL-PLANT-AIR MOISTURE TENSIONS

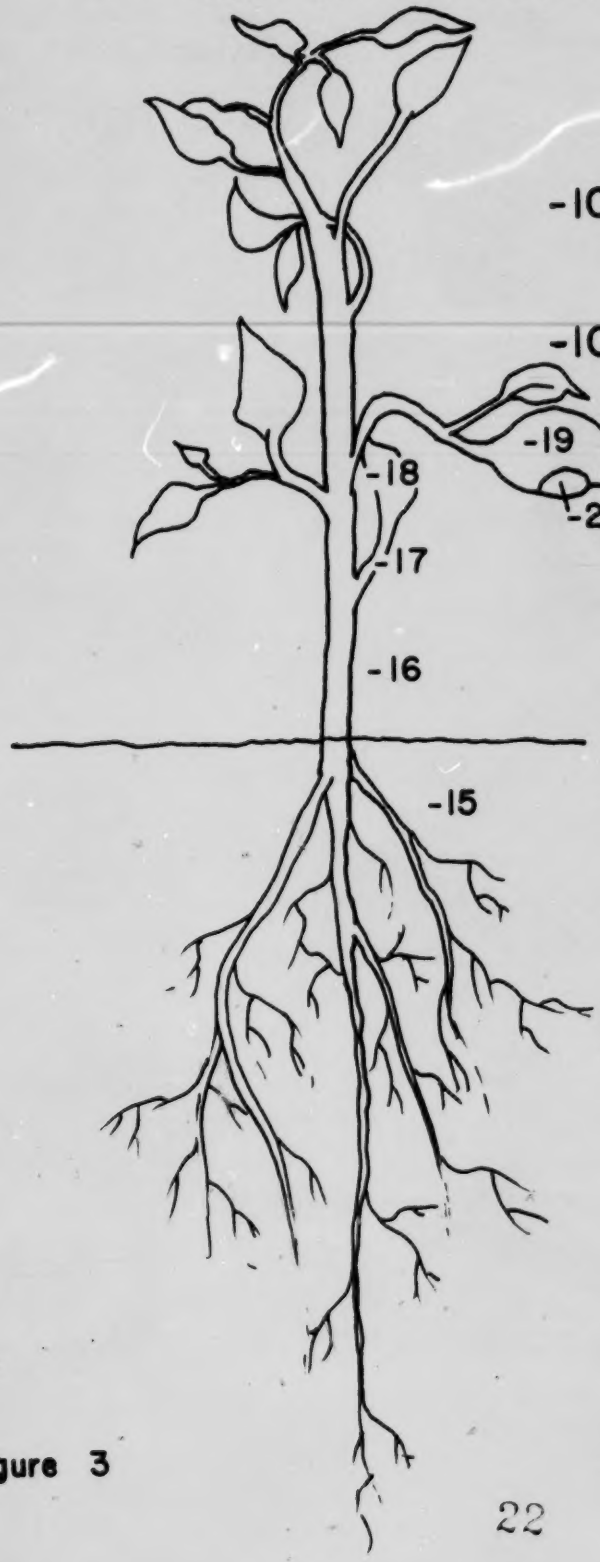

Figure 3

Net radiation may be calculated on the basis of information available in tables and measurements of temperature and net solar radiation (Tanner, 1974). Table 5 indicates sources of available information. Solar radiation measurements have been made at only a few weather stations, however, they may be made conveniently and inexpensively in a fashion similar to that of Kerr et al. (1967).

Relative humidity, wind velocity and turbulence influence the amount of advected energy. Heat exchange will be influenced by the aerodynamic relations of the crop canopy. Open row crops can increase surface area, turbulence, and mixing and hence evaporation.

Determination of Evapotranspiration Using Climatic Data

ET may be determined accurately with micrometeorological (energy budget) methods, lysimeters, and soil water measurements. Because of the expense of equipment and/or labor involved with these methods, simple climatological estimates of ET have been developed. All purely climatological methods estimate the potential evapotranspiration, ET_p, that would be produced by the prevailing climate if available moisture were not limiting, which is usually the case within a land application site. The climatological estimate may be modified by various schemes to account for the influence of declining soil water on evaporation and transpiration.

ET may be determined with micrometeorological methods, lysimeters and soil water measurements. It may be estimated with climatological data to give potential evapotranspiration (ET_p)

The empirical climatological methods can be divided into groups according to the measurements which they require: temperature correlation, radiation methods, humidity methods, and pans and atomometers.

Temperature Correlations: Their main value has been in estimating ET in areas where the only climatic record is temperature.

Table 5. Principal Federal sources of data useful in planning and operation of irrigation developments served from surface sources

Type	Agency
Humidity	WB,* FS, TVA, IBWC, ARS
Pan evaporation	WB,* BR, IBWX, TVA, CE, ARS, FS
Precipitation	WB,* TVA, IBWC, SCS, ARS, FS, BR, CE
Chemical quality of water	GS,* PHS, BR, ARS, TVA, IBWC
Suspended load	GS,* BR, TVA, CE, IBWC, ARS, PHS
Reservoir sedimentation	SCS, BS, BR, TVA, CE, ARS, FS
Snow	SCS,* WB,* CE, FS, BR, TVA, ARS, MPS
Solar radiation	WB,* ARS, BR, FS
Streamflow	GS,* ARS,* IBWC,* BR, CE, FS, TVA
Temperature air	WB,* ARS, IBWC, TVA, FS
Wind	WB,* TVA, ARS, CE, FS, BR
Soils	SCS,* FS, BLM, BIA, ARS
Topography	GS*
Geology	GS*
Land use	BC,* ERS, FS, SCS, BLM, BIA, SRS

* Asterisk indicates agencies that regularly publish data. Other agencies publish data intermittently in research or other reports.

Key to agencies:

Department of Agriculture
- ARS - Agricultural Research Service
- ASCS - Agricultural Stabilization and Conservation Service
- ERS - Economic Research Service
- FS - Forest Service
- SCS - Soil Conservation Service
- SRS - Statistical Reporting Service

Department of the Interior
- BIA - Bureau of Indian Affairs
- BLM - Bureau of Land Management
- BR - Bureau of Reclamation
- GS - Geological Survey
- NPS - National Park Service

Department of Commerce
- BC - Bureau of Census
- WB - Weather Bureau

Department of Health, Education and Welfare
- PHS - Public Health Service

Department of the Army
- CE - Corps of Engineers

Other Federal Organizations
- IBWC - International Boundary and Water Commission, United States and Mexico
- TVA - Tennessee Valley Authority

Source: Wilcox and Duram, 1967

a) Blaney-Criddle (1950): assumes a linear relationship between ET_p and temperature.

$$ET_p = CL_dT$$

C is a monthly "consumption use" crop and location coefficient, L_d is a day length factor, and T is mean temperature. This formula was derived in the irrigated west and has been used for many years. Tables are available. Blaney-Criddle is not a good estimator of short term water demand but is an empirical estimator of the area for which it was developed. A complete discussion of the Blaney-Criddle formula, including modifications for short-term use, is found in Appendix B of Module 8, "Climate and Wastewater Storage".

Temperature correlation methods for estimating ET_p are easy to use but lack accuracy for short term ET. These can be used when only temperature records are available.

b) Thornthwaite (1948): assumes non-linear relation between ET_p and temperature.

$$ET_p = 1.6\ (10\ T/I)^a$$

T is mean temperature, I is a month heat index (available in Tables) and "a" is a function of I. This formula was derived in the humid east. Like other mean temperature methods it is not satisfactory for ET modeling on a short term basis. The Thornthwaite method underestimated ET by about 50% during the growing season at Davis, California.

The other methods are more complex, but yield more accurate short and long term ET_p information. These include the methods developed by Penman, Priestley and Taylor, and Tanner. A local college of agriculture can provide the information necessary to use these formulas. In land application systems accurate estimates of evapotranspiration along with known amounts of precipitation and applied wastewater would allow good estimates of the volume of water percolating through the root zone.

Figure 4 demonstrates several relationships which exist between soil moisture tension and available water depletion. Uisng Figure 4 together with the data contained in Table 6 allows a reasonable approximation of

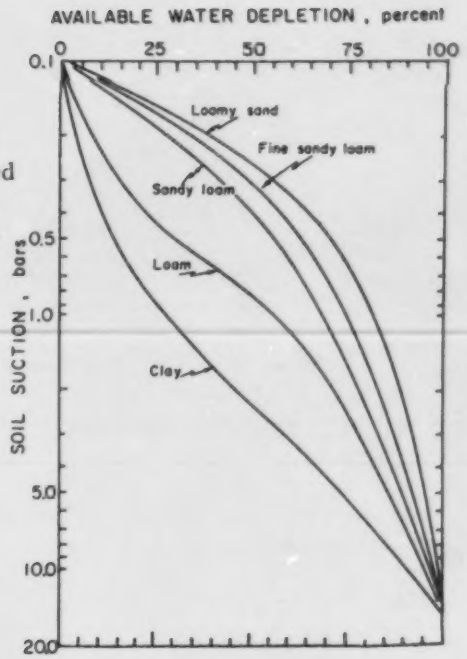

Figure 4. Water retention curves for several soils plotted in terms of percent available water removed.

Source: Haise and Hagan, 1967

available water held by a given soil type at any given soil moisture tension. Table 7 illustrates the soil moisture tensions at which water should be applied to produce maximum yields (satisfy potential evapotranspiration). The range of values given for each crop recognizes the effects of high and low evaporative demand and expected weather conditions. Table 8 indicates typical values of ET observed with various crops and depths of root penetration.

The amount of data on available moisture for different soil types, soil moisture tension, the moisture tension for each crop at which water should be applied and daily ET can be used to approximate the amount of wastewater that crops need for optimum production.

The utility of this information will be evident from an example: consider potatoes grown on a sandy

Table 6. Typical range of available soil moisture by soil textural class

	Available Soil Moisture Storage[1]	
	Range	Average
	in/ft	
Very coarse textured sands and fine fine sands	0.50-1.00	0.75
Coarse textured loamy sands and loamy fine sands	0.75-1.25	1.00
Moderately coarse textured sandy loams and fine sandy loams	1.25-1.75	1.50
Medium textured very fine sandy loams, loams, and silt loams	1.50-2.30	2.00
Moderately fine textured sandy clay loams and silty clay loams	1.75-2.50	2.20
Fine textured sandy clays, silty clays and clays	1.60-2.50	2.30

[1] Storage between field capacity (1/10 to 1/3 ATM) and wilting point (15 ATM).

Source: Metcalf and Eddy, Inc., 1977.

Table 7. Soil water suction at which water should be applied for maximum yields of various crops grown in deep, well drained soil fertilized and managed for maximum production.

Crop	Soil Suction, bars
Vegetative crops	
Alfalfa	1.50
Beans (snap, lima)	0.75-2.00
Cabbage	0.60-0.70
Canning peas	0.30-0.50
Celery	0.20-0.30
Grass	0.30-1.00
Lettuce	0.40-0.60
Tobacco	0.30-0.80[a]
Sugar cane	0.25-0.30
Sweet corn	0.50-1.00
Root crops	
Onions, early	0.45-0.55
Onions, bulbing	0.55-0.65
Sugar beets	0.40-0.60
Potatoes	0.30-0.50
Carrots	0.55-0.65
Broccoli, early	0.45-0.55
Broccoli, postbud	0.60-0.70
Cauliflower	0.60-0.70
Fruit crops	
Lemons	0.40
Oranges	0.20-1.00
Deciduous fruit	0.50-0.80
Avocadoes	0.50
Grapes, early	0.40-0.50
Grapes, mature	1.00
Strawberries	0.20-0.30
Cantaloupe	0.35-0.40[a]
Tomatoes	0.80-1.50[b]
Bananas	0.30-1.50[b]

(continued on next page)

Table 7 (continued).

Crop	Soil suction, bars
Grain crops	
Corn, vegetative	0.50
Corn, ripening	8.00-12.00
Small grains, vegetative	0.40-0.50
Small grains, ripening	8.00-12.00
Seed crops	
Alfalfa, prebloom	2.00
Alfalfa, bloom	4.00-8.00
Alfalfa, ripening	8.00-15.00
Seed carrots, 60-cm depth	4.00-6.00[c]
Onions, 7-cm depth	4.00-6.00[c]
Seed onions, 15-cm depth	1.50
Lettuce, productive	3.00[c]
Coffee requires short periods of low potential to break bud dormancy, followed by high water potential	

* Where two values for soil water suction are given, the lower suction value is used when the evaporative demand is high and the higher value when it is low; intermediate values are used when the atmosphere demand for evapotranspiration is intermediate. (these values are subject to revision as additional experimental data become available.)

[a] Based on converting 50% available water to water potential (soil suction) equivalents using curves for appropriate soil textures.

[b] Based on converting 70% available water to water potential (soil suction) equivalents using curves for clay soils.

[c] Resistance values were converted to water potential from calibration of similar plaster resistance units.

Source: Haise and Hagan (1967)

Table 8. --Design moisture-extraction depth and peak-period consumption-use rate for various crops grown on deep, medium-textured, moderately permeable soils[1]

Crop	Wisconsin (State)		Indiana (State)		Piedmont Plateau[2]		Virginia (Coastal Plain)		New York (State)	
	Depth	Use Rate	Depth	Use Rate	Depth	Use Rate	Depth	Use Rate	Depth	Use Rate
	In.	In. per day	In.	In. per day	In.	In. per day	In.	In. per day	In.	In. per day
Corn	24	0.30	24	0.30	24	0.22	24	0.18	24	0.20
Alfalfa	36	.30	36	.30	36	.25	36	.22	30	.20
Pasture	24	.20	30	.30	24	.25	20	.22		
Grain	18	.25			24	.16				
Sugar beets	18	.25								
Cotton					24	.21				
Potatoes	18	.20	12	.25	24	.18	18	.18	18	.18
Deciduous orchards	36	.30			36	.25	36	.22	36	.20
Citrus orchards										
Grapes			24	.25	30	.20				
Soybeans	18	.25	24	.30	24	.18				
Shallow truck	12	.20	9	.20	12	.14			12	.18
Medium truck	18	.20	12	.20	18	.14	18	.16	18	.18
Deep truck	24	.20	18	.20	24	.18			24	.18
Tomatoes	18	.20	18	.20	24	.21	24	.18	24	.18
Tobacco			24	.25	18	.18	18	.17		

[1] From current irrigation guides

[2] Parts of Georgia, Alabama, North Carolina, and South Carolina.

Source: SCS, 1964.

loam soil. Potatoes are shallow rooted and require about 0.2 inches of water per day. They should be irrigated when soil moisture tensions are about 0.4 bars. A sandy loam will yield 50% of its available moisture capacity before soil moisture tensions reach 0.4. A moderately coarse textured sandy loam stores on average 1.5 inches/foot. If the roots explore a depth of 18 inches, containing 2.25 inches of "available moisture", they would use up 50% of this moisture in less than 6 days. For maximum yields these potatoes would require irrigation or precipitation more often than once a week no matter how much water was applied. They would require water applications providing 1.4 inches/week available in the root zone. If potatoes were grown on a loam soil, where 0.4 bars is reached at 25% water depletion and about 3 inches of "available moisture" is stored in a depth of 18 inches, 25% of 3 inches is 0.75 inches and this would be used in only 4 days. Additions of 0.8 inches of precipitation or irrigation water would be needed every 3-4 days. In such a situation, care would have to be taken to ensure even distributions of water and avoid waterlogging of low spots in the field.

Drainage Requirements and Crop Water Tolerance

For many years agriculturalists have recognized that excess water in the root zone resulted in reduced crop growth and more difficult and less timely field operations. The benefits to be derived from the removal of excess water were summarized by Van't Woudt and Hagan (1957) (Table 9). Drainage has usually allowed greater early crop growth, an advantage for wastewater application in which the object is to apply the most wastewater consistent with renovative capacity. Thus drainage, by removing water, can increase a field's irrigation requirement.

Drainage can allow earlier, more rigorous crop growth. This improves renovative capacity and increases the amount of wastewater that can be applied.

When equipment is driven over a wet soil, the soil can be compacted and macropore space is reduced. A compacted layer will aggrevate the problems of wet fields by:

1) restricting water percolation
2) restricting root penetration
3) restricting gaseous diffusion
4) reducing the effective volume of soil available for renovation.

Soil compaction - resulting in lower percolation - can be protected against by crop selection and cultural practices.

Following a rain or irrigation a soil may appear dry in the top two or three inches and yet be too wet for successful tillage. The weather is always uncertain, and allowing the soil to dry sufficiently for field operations to be completed will demand cessation of water applications for variable periods of time. Cropping systems and cultural practices which minimize field traffic should minimize compaction problems. Sod crops generally have greater efficacy in maintaining soil structure than have cultivated crops, if care is taken not to harvest forage when the soil is too wet.

Table 9. Benefits to be derived from the removal of excessive soil moisture.

Item #	Description of benefit
1	Improved aeration
2	Improved nitrogen economy in the soil
3	Increased benefit from topdressing, particularly phosphorus
4	Increased activity of earth worms
5	Reduced weed infestation
6	Improved workability of the soil
7	Increased depth of rooting
8	An earlier warming up of the surface soil, leading to a prolonged growing season
9	Improved soil structure
10	Increased storage capacity of the soil and increased infiltration rate of the soil, and therefore reduced erosion
11	Prevention of damage to roots by frost heaving
12	Increased availability of moisture during a dry spell because of deeper root penetration leading to increased drought resistance of plants on drained soils
13	Prevention of alkali accumulation
14	Decreased danger of plant diseases
15	Improved public and animal health

Source: Van't Woudt and Hagan, 1957.

In a land application system a significant fraction of the water applied may be intended for percolation. The amount of such water may be quite variable and could be limited by the ability of a given soil to drain the root zone within one or two days, or by the nitrogen or phosphorus concentrations of the percolate. These limitations will be compared in the subsequent section, "Crop Tolerances to Nutrients, Salts, and Toxic Elements".

As discussed in Module 17, "Organic Matter", aeration of the soil depends primarily on diffusion within the air-filled pore space. Diffusion within the liquid phase is very slow. The diffusion coefficient of oxygen in water is about 2.56×10^{-5} cm^2/sec. and about 1.89×10^{-1} cm^2/sec. in air. Diffusion through saturated soils is even slower than that through water (Letey et al., 1967). When a soil becomes flooded, respiration of roots and microorganisms within the soil can quickly exhaust the available oxygen. High temperatures accelerate the depletion. If the soil can drain efficiently and fresh air refills the pore space, brief flooding should not reduce crop growth. If flooding persists, O_2 concentrations will decline and CO_2 increase. This may directly influence crops by reducing root growth, water absorption and nutrient absorption. Following irrigation, entrapped air within the flooded root zone may maintain aerobic conditions for a day or two. The water table during the period from about two days after irrigation until the next irrigation is, therefore, critical for plant production (Van den Berg, 1973). This emphasizes the importance of soil porosity and drainage characteristics.

Oxygen is rapidly depleted from a flooded soil, CO_2 increases. This can reduce root growth, water, and nutrient adsorption, as well as create the potential for toxic compounds to be formed, and phosphorus and potentially toxic elements to be mobilized.

According to Letey et al., (1967) the roots of many species will not grow in an environment where the oxygen diffusion rate is less than about 0.20 $\mu g/cm^2$/min. (about 12 lbs/acre/24 hours). In a study conducted in the San Joaquin Valley of California, oxygen diffusion rates were measured at various times and depths after irrigation and at various distances from a wetted furrow (Figure 5).

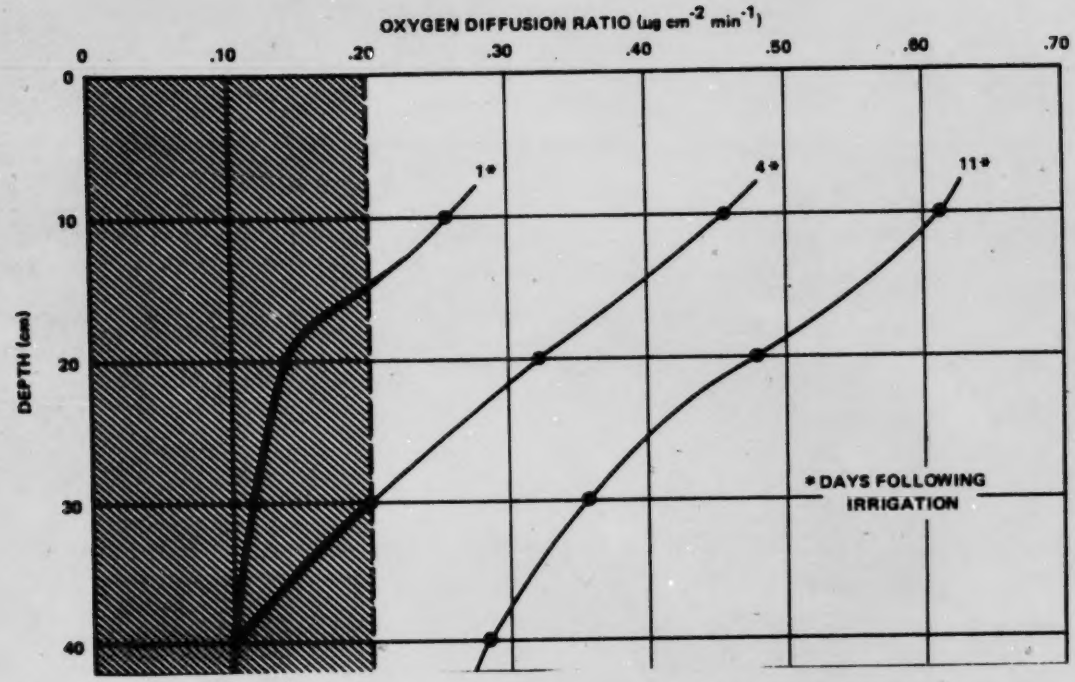

Figure 5. Oxygen diffusion rate (ODR) as a function of soil depth on various days following irrigation in a cotton field.

In this experiment, conducted on a Panoche clay loam, the ODR was adequate for good root growth to a depth of less than 30 cm on the 4th day after irrigation. In the same experiment, the ODR under sprinkler irrigation was slightly higher than furrow irrigation, but not significantly higher. In other experiments the rate of recovery of ODR has been shown to be dependent on crop rotation and cultural practices. The natural porosity characteristics of a soil are probably the most important factor influencing soil aeration.

In addition to the direct effects attributable to low O_2 and high CO_2 levels under anaerobic conditions, toxic organic compounds may be formed and phosphorus and toxic elements may be mobilized. The effect of water-logging on crops has been shown to be affected by crop, variety, stage of growth, temperature, light intensity,

The effect of water-logging on crops is affected by crop, variety, stage of growth, temperature, light intensity, and fertility.

and fertility (Grable, 1966). It is therefore difficult to make meaningful generalizations, as can be seen by studying Figure 6 which indicates response of several crops to flooding. Complete information on the response

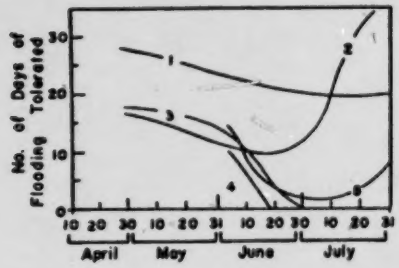

FIG. 6 The estimated number of days flooding is tolerated by various crop plants at different times during the growing season under Finnish conditions, without the plants being destroyed 1—timothy; 2—rye; 3—clover; 4—barley; 5—oats.

(Van't Woudt and Hagan, 1957)

of each crop to these variables is not recorded. Some practical experience is available. Reviews of available information have been published by Russell (1952), Van't Woudt and Hagan (1957), Letey et al. (1967), Van den Berg (1973), and Wesseling (1974).

Root Systems Are Adapted to Particular Soil Water Conditions

It has been observed from these and other experimental results that small grains are most tolerant of flooding at early stages of growth and when approaching maturity. Most perennial grasses can tolerate some flooding when dormant, although frost heaving of tap rooted crops may be a serious problem under these conditions in cold areas. The tolerance of most crops

declines as temperatures rise and growth commences. Most crops are especially sensitive as they approach flowering. Some grasses appear to be the most tolerant of all crops. Shallow rooted clovers are among the least tolerant to flooded soils.

Crops, in varying degress, develop roots adapted to saturated conditions. The most adapted to these conditions is rice, which is specialized for flooded fields. Some species have roots which will penetrate through a well aerated profile and extend below the saturated capillary fringe. These plants include alfalfa, sweet clover, soybeans, rye grass, wheat, and some fruit trees on special rootstock. These plants, however, do not necessarily demonstrate tolerance to flooding as does paddy rice. Other crops, including sugar cane, barley, corn, oats and tomatoes, respond to poor aeration by developing roots which are similar to those of rice. The tolerance of these crops to flooding is variable.

Some plant species develop root systems adapted to saturated conditions. However, they may not be adapted to flooded conditions. Other crops develop root rot and therefore cannot tolerate saturated conditions.

In some crops such as corn and sorghum the most susceptible stage to damage by flooding is the seedling stage. This may be a temperature effect. In later stages of growth, corn can tolerate some flooding and sorghum is even more tolerant (Robins, 1967). Cotton and grain sorghum are unusual in that they may be flooded for several days during hot weather without being destroyed. Sugar cane and rice are the most adapted crops if waterlogged conditions are likely to prevail. These crops are commonly grown at land application sites in arid areas.

The effect of wet soils on crops differs according to the species and the stage of growth of particular species.

Among the grasses, Dallas grass, Reed canary grass, tall fescue and timothy appear to be the best adapted to moist conditions, much more so than ryegrass and orchardgrass (Van't Woudt and Hagan, 1957). Narrow leaf trefoil is the most tolerant legume grown under irrigation in California. The adaptation of different varieties within a species can be quite variable.

Disease and Insect Breeding Conditions Are Enhanced in Wet Soils

Irrigation can cause plant disease and insect problems. This problem is less severe with ridge and furrow irrigation. "Scalding" damage is possible where high temperatures prevail, although some crops are resistant to scald.

Under irrigation, favorable moisture relations increase the potential for disease and insect problems and these should be considered in the crop selection process. Menzies (1967) has reviewed the disease problem and Klostermeyer (1967) that of insects. Long low rates of water application or supplemental irrigation in already humid climates may maintain an environment for spore germination, infection and sporulation for secondary infections. Other types of irrigation present more of a problem in this regard than furrow irrigation because they wet the foliage and spread spores. In arid areas, however, experience has shown that disease problems did not develop with the anticipated degree of severity. Insect problems have been serious in various places, and are one of the reasons alfalfa is often left unirrigated during 2-3 summer months in Arizona (Van't Woudt and Hagan, 1957). For information on controlling insects consult a state college of agriculture , USDA office or agricultural extension personnel.

A final problem under irrigation is "scalding" damage. As reviewed by Van't Woudt and Hagan (1957), "scalding" (also known as "white spot disease") is the other major reason why alfalfa in Arizona is left unirrigated. "Scald" is associated with conditions of excessive moisture when high temperatures prevail. Symptoms develop suddenly, 12 to 24 hours after irrigation or heavy rain. Chlorophyll is destroyed first between leaf veins and along leaf margins. Entire leaves and entire plants may be affected with a resultant reduction in stand. The mechanisms involved in producing scald characteristics are not well understood, but ponding aggravates the situation. The following crops tend to be subject to "scalding": sweet clover, ladino clover, strawberry clover, birdsfoot trefoil, potatoes, barley, beans and lettuce. Alsike clover, Reed canary grass and Dallas grass were reported to be relatively resistant to scalding.

Nutrient Removal and Renovation Efficiency

One of the primary objectives of land application is the removal of soluble nitrogen and phosphorus. When applied to land to fertilize vegetation, if the vegetation is not removed, then nutrients will recycle within the biomass, accumulate, and in spite of increased denitrification, eventually "leak" to the environment in drainage waters. The removal of macro- and micro-nutrients allows higher nutrient application rates without environmental degradation, and can be regarded as prolonging the effective life of a site as a waste treatment medium. If nutrients are applied only to meet crop requirements, then the site should remain effective indefinitely.

Weeds or natural vegetation could be allowed to grow in lieu of a crop on a land treatment site and would take up nutrients which would be removed if the weeds were themselves cut and removed. There is some doubt about the amount of nutrients which may be assimilated by weeds, but weeds are fast growing and vigorous competitors for water and nutrients. To the extent that weeds are quick to mature, they might not make advantageous use of the full growing season. Perhaps the biggest drawback to the use of weeds for nutrient uptake is the lack of a ready market for the harvested product. However, as pointed out by Wolcott and Cook (1976), certain weeds may nevertheless be useful in certain situations. In forage crops, quackgrass (Agropyron repens L) is often already established in many fields and forms on rhizome-laced sod which may help hold alfalfa from frost heaving and heavy equipment from rutting the field. Reed canary grass, though slow to establish from seed, also forms a tough rhizome sod.

Weeds might be advantageous for nutrient uptake and ease of establishment. There may not be a ready market for the harvested crop.

Tables 10 and 11 represent some of the values reported by various workers for yields and nutrient

uptake of agronomic crops. In general it may be observed that crops take up only about 1/8 to 1/10 as much phosphorus as nitrogen. Potassium uptake by forage crops may be close to that of nitrogen but much of this is returned as crop residues if only edible seeds are removed. Forage crops also remove greater amounts of minor elements and trace elements from a soil than do edible seeds.

Crops vary in the amount of nitrogen and phosphorus taken up. These figures range from 72 to 450 lbs N/acre depending upon the part of the plant harvested, the type of crop and the yield.

Based on the information contained in Tables 10 and 11, comparisons of land area requirements, nutrient loading, and hydrologic loading can be made. Table 12 considers a design flow of 1 MGD, typically produced by 10,000 people. This design flow is with typical municipal sewage.

Table 10. Harvested Removal of Nutrients for Selected Crops and Yield Goals

Crop Yields and Nutrients Harvested, Lb./Acre

Nutrient	Corn Grain	Corn Silage	Wheat Grain	Soybeans	Alfalfa-Brome	Reed Canary Grass	Hardwood Forest (Annual Uptake, Lb./Acre)
Yield	150 bu.	25 T.	60 bu.	35 bu.	5 T.	5.5 T.	
Nitrogen	125	165	72	120	220	408	84
Phosphorus	22	30	13	12	30	56	8
Potassium	28	150	14	36	166	247	26
Calcium	3	45	2	5	90	44	22
Mag sium	10	30	4	6	37	40	5

Source: Wolcott and Cook (1976)

Table 11. Annual Nitrogen, Phosphorus, and Potassium Utilization by Selected Crops*

Crop	Yield	Nitrogen	Phosphorus	Potassium
Corn	150 bu.	185	35	178
	180 bu.	240	44	199
Corn silage	32 tons	200	35	203
Soybeans	50 bu.	257[1]	21	100
	60 bu.	336[1]	29	120
Grain sorghum	8,000 lb.	250	40	166
Wheat	60 bu.	125	22	91
	80 bu.	186	24	134
Oats	100 bu.	150	24	125
Barley	100 bu.	150	24	125
Alfalfa	8 tons	450[1]	35	398
Orchard grass	6 tons	300	44	311
Brome grass	5 tons	166	29	211
Tall fescue	3.5 tons	135	29	154
Bluegrass	3 tons	200	24	149

* Values reported above are from reports by the Potash Institute of America and for the total above-ground portion of the plants. Where only grain is removed from the field, a significant proportion of the nutrients is left in the residues. However, since most of these nutrients are temporarily tied up in the residues, they are not readily available for crop use. Therefore, for the purpose of estimating nutrient requirements for any particular crop year, complete crop removal can be assumed.

[1] Legumes can get most of their nitrogen from the air, so additional nitrogen sources are not normally needed. There is evidence that alfalfa utilizes the nitrogen applied in wastewater when it is available.

Source: Sommers and Nelson (1976).

Table 12. Hydraulic and Nutrient Loading at Various Application Rates*

Flow = 1 MGD
Pop. = 10,000
Total yearly flow ≅ 1000 acre-foot

in/wk	Land Area Required	ac-in/ ac-yr	lb-N/ ac-yr	lb-P/ ac-yr	lb-K/ ac-yr	lb-Zn/ ac-yr
0.4	1000 (acres)	12	116	49	43	3.8
0.8	500	24	232	98	86	7.6
1.2	330	36	348	147	129	11.4
1.6	250	48	464	196	172	15.2
2"/wk	200	60	580	245	215	19.0

Wastewater Characteristics: N-43 mg/ℓ, P-18 mg/ℓ, K-16 mg/ℓ, Zn-1.5 mg/ℓ which can be considered medium strength untreated sewage.

* applied over 30 weeks in addition to natural precipitation.

In humid areas, 12 inches/acre/year in addition to natural precipitation should, when applied as needed, meet ET requirements of most crops. Twelve inches/acre/year will also contribute substantially to the fertilizer requirements of most crops, although supplemental potassium would be required if forage crops were to be harvested regularly and supplemental nitrogen would be needed to supply the peak uptake demands of a corn crop. The utilization efficiency of the nutrients applied should be good, particularly if the wastes are applied during the hottest part of the growing season, and if applied in a fashion which does not injure the crop. Larger amounts, up to 0.3 inches of water per day, are needed in arid areas for optimal crop growth. Larger amounts can be applied in humid areas as well, as long as percolation through the desired rooting depth is accomplished within about two days so that soil aeration is not restricted. When 24 inches or more of wastewater is applied during the growing season, phosphorus and zinc will begin to accumulate and may eventually limit the ability of the site to renovate wastewaters and to produce crops under general farming. At the rates cited in Table 12, it is highly unlikely that a site receiving domestic wastes would be limited for phosphorus removal until well past the site design period. During this period the total amount of phosphorus in the plow layer may be doubled and redoubled. Phosphorus will also be increased at lower soil depths. Evidence suggests, however, that the ultimate reversion products of phosphorus are very stable (Taylor and Kunishi, 1974). Module 19, "Phosphorus Considerations" discusses this aspect of land treatment in detail.

Potentially Toxic Element Uptake Can be Beneficial in Lower Concentrations

Nitrogen uptake by a crop is a passive process and may be regarded as a function of transpiration and the nitrogen concentration of the water transpired. The incorporations of nitrate into amino acids, and the uptake of cations from the soil solution, on the other hand, are active aerobic processes dependent upon available photosynthate and oxygen. Plants demonstrate varying degrees of selectivity in the active uptake and translocations of cations to above ground plant parts and especially to reproductive organs. These observations have practical implications in that high nitrate forages can be toxic to livestock and seeds, fruits and edible roots tend to exclude toxic elements.

Plants actively and selectively take up potentially toxic elements. These elements are also selectively transported to the various plant parts. This results in different plants and the parts within the plants having varying concentrations of potentially toxic elements.

The uptake and harvest of potentially toxic elements may seem undesirable from the standpoint of protecting the food chain. Uptake and removal in non-toxic (i.e., normal) concentrations, however, might be thought to prolong site longevity. Taking Zn as an example of a potentially toxic element, however, it is evident that the amounts applied in waste (Table 12) are large compared to the less than 0.5 lb of Zn per acre removed in most harvested crops, and large compared to the amounts added as fertilizers to alleviate deficiencies. Allaway (1975) has indicated that fertilizers supplying as little as 10 pounds of Zn per acre can produce optimum crop growth although heavier applications are needed to increase food and feed crops as sources of dietary Zn. A considerable margin of safety exists between the rates used to increase levels of dietary Zn and those which result in plant toxicity and yield reduction. Typical estimates of "safe" amounts would allow application of domestic wastewater for a number of years (Table 13). Heavily contaminated urban/industrial wastewaters, on the other hand, may exceed these limits in a short time.

A considerable margin of error exists between safe and unsafe application levels of potentially toxic elements.

Table 13. Total Amount of Sludge Metals Allowed on Agricultural Land

Metal	Soil Cation Exchange Capacity (meq/100 g)*		
	0 - 5	5 - 15	>15
	Maximum Amount of Metal (Lb./Acre)		
Pb	500	1000	2000
Zn	250	500	1000
Cu	125	250	500
Ni	50	100	200
Cd	5	10	20

* Determined by the pH 7 ammonium acetate procedure.

Source: Sommers and Nelson (1976)

Turf grass sod and ornamental nursery production has an apparent advantage on sludge and wastewater disposal sites in that a good deal of soil is harvested and removed with each crop. While this tends to deplete soils at unamended sites, on a land application site the removal of nitrogen, phosphorus and toxic elements in these specialty crops at rates much higher than in agronomic crops would be a decided advantage in extending site longevity. Spreading these elements over landscaped areas would tend to remove the contained toxic elements from food chains. The net result would be similar to that achieved if sludge were dried or compacted and sold as a soil amendment to landscapers and golf courses.

Irrigating sod and ornamental nursery stock for transplanting can extend site life and allow higher rates of waste application.

Aside from specialty crops in which soil is harvested, and while influenced by many factors including plant species and soil ionic balances, nutrient uptake into crops remains a function of crop growth. Farmers generally grow the crops best adapted to the length of season and amount of available moisture in their fields. Crop

selection for maximum growth and nutrient uptake at land application sites, where available moisture should be abundant, will be limited primarily by yearly temperature fluctuations and solar energy.

Crop selection is limited by temperature fluctuation and solar energy at a land application site.

Perennial crops have an advantage in that they can begin growth and develop a crop canopy as early in the year as temperatures permit. They do not have to wait for preparatory tillage operations which can be delayed by wet weather. Perennials' early growth is also rapid because they often enter the growing season with considerable food reserves.

Perennial crops begin growth early and do not have to wait for preparatory tillage.

Figure 7 and Table 14 indicate how climatic regions influence the distribution of grass species grown in the United States. (The same type of information concerning legumes can be found in Kipps, 1970).

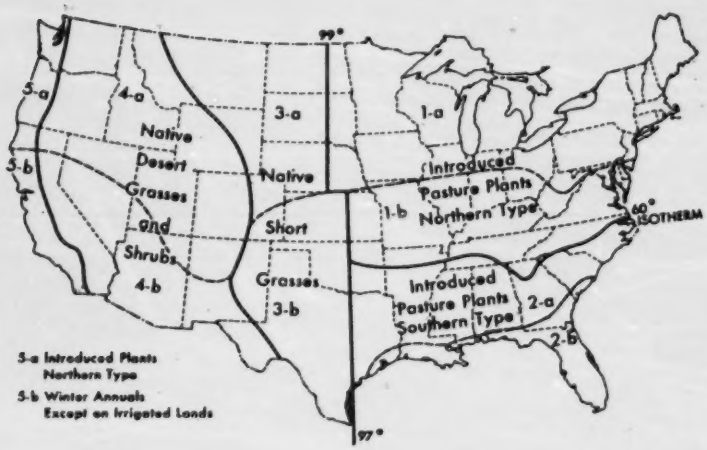

FIG. 7 Map showing the five natural pasture regions, determined largely by climate, of the United States, and the types of pasture plants that provide most of the pasturage in each. Each region is divided into sections *a* and *b*, mainly because of temperature relations, except on the Pacific Coast. Here section 5*a* is the more or less humid Northern area, and 5*b* the rather arid Southern area. (*U.S. Dept. Agr. Misc. Pub. 194. 1948.*)

TABLE 14 INFORMATION REGARDING GRASSES FOR PERMANENT PASTURES (USDA, 1946)

Name	Climatic adaptation*	Degree of palatability	Season for grazing	Time and rate of seeding per acre, lb	Soil adaptation†	Remarks
Bahiagrass (*Paspalum notatum*)	Section 2-b	High	Early spring to late fall	Early spring, 10–15	Sandy loam to sand	Seed expensive and of low germination
Bermudagrass (*Cynodon dactylon*)	Region 2 and sections 3-b and 4-b	Medium	Late spring to early fall	Early spring, 5–8	Loams, clays, and silts	Propagated to a large extent vegetatively
Bromegrass or smooth brome (*Bromus inermis*)	Western part of section 1-a and sections 3-a and 4-a	High	Very early spring to late fall	Early spring or early fall, 15–20	Practically any type	Excellent grass for use with alfalfa
Canada bluegrass (*Poa compressa*)	Region 1-a and sections 3-a and 4-a	High	Early spring to late fall	Early spring or fall, 15–20	Almost any type	Succeeds on poor soils
Carpetgrass (*Axonopus compressus*)	Region 2	Medium	Spring to fall	Early spring, 8–12	Moist sands or sandy loam	Makes a very tight turf
Centipedegrass (*Eremochloa ophiuroides*)	Southern half of region 2	Medium	Spring to fall	Early spring; use sod or stolons; no seed available	Almost any type	Makes a close turf and is very aggressive, when once established, crowding out weeds, legumes, and other grasses
Crested wheatgrass (*Agropyron cristatum*)	Sections 3-a and 4-a	High	Very early spring to late fall	Early spring, 12–15	Almost any type	Drought resistant; easy to get a stand
Dallisgrass (*Paspalum dilatatum*)	Region 2 and sections 3-b, 4-b, and 5-b where irrigated	High	Early spring to late fall	Early spring or fall, 8–12	Any fairly productive soil	Seed expensive and often of low germination; difficult to get a stand
Johnsongrass (*Sorghum halepense*)	Region 2 and section 3-b; also sections 4-b and 5-b where irrigated	High	Spring to fall	Early spring, 20–25	Loams and clays	Productiveness decreases rapidly when grazed; very difficult to eradicate
Kentucky bluegrass (*Poa pratensis*)	Region 1 and section 5-a; also sections 3-a and 4-a where moisture is plentiful	High	Spring to late fall	Early fall, 15–20	Sandy loams to clays of high productivity	The leading pasture grass on good soils in the North
Meadow fescue (*Festuca elatior*)	Region 1 and section 5-a; also sections 3-a and 4-a where moisture is plentiful	High	Early spring to late fall	Early fall, 20–25	Loams to heavy clays	Valuable in section 5-a; of limited value elsewhere, disappearing rather quickly except on heavy, moist clays
Meadow foxtail (*Alopecurus pratensis*)	Sections 1-a and 5-a; also 4-a at high altitudes	High	Early spring to late fall	Early fall, 20–25	Moist sandy loams to clay	Very useful in pasture mixtures on wet soils, especially in 5-a
Orchardgrass (*Dactylis glomerata*)	Region 1; also sections 3-a, 4-a, and 5-a where moisture is plentiful	Medium to high	Early spring to fall	Early fall or early spring, 20–25	Any soil type except sand, if not too wet	Inclined to grow in bunches unless seeded thickly
Paragrass (*Panicum purpurascens*)	Section 2-b	High	Spring to fall	Early spring, no seed available	Wet soils	Propagated by planting pieces of stem or sod
Perennial ryegrass (*Lolium perenne*)	Southern half of region 1 and in section 5-a	High	Early spring to late fall; winter grazing in section 2-a to limited extent	Very early fall (or spring in the North), 20–25	Sandy loams to clays of medium to good fertility	Used but little in pasture except in section 5-a and in New England States
Redtop (*Agrostis alba*)	Regions 1, 2, and section 5-a; also under irrigation and in mountain meadows, sections 3-a and 4-a	Medium	Early spring to late fall	Early fall best, early spring fair, 10–12	Grows on majority of soil types; prefers moist soils	Of most value on poorly drained soils too wet for other grasses
Reed canarygrass (*Phalaris arundinacea*)	Sections 1-a and 5-a; also sections 3-a and 4-a where moisture is plentiful	Medium	Spring to fall	Very early spring, 8–12	Loams to heavy clays	Very good for wet lands, will endure submergence

(continued on next page)

TABLE 14 INFORMATION REGARDING GRASSES FOR PERMANENT PASTURES *(Continued)*

Name	Climatic adaptation*	Degree of palatability	Season for grazing	Time and rate of seeding per acre, lb	Soil adaptation†	Remarks
Rescuegrass (*Bromus catharticus*)	Region 2, and where moisture is sufficient in sections 3-b and 4-b	Medium	Fall to spring (winter pasture)	Early fall, 20–25	Sandy loam to clay loam	An annual used in some localities for winter and spring grazing
Rhodesgrass (*Chloris gayana*)	Section 2-b; also southern parts of sections 3-b and 4-b	Medium	Spring to fall	Spring, 10–12	Loams to clays	Found most useful in the dry sections of southern Texas where other grasses fail
Slender wheatgrass (*Agropyron pauciflorum*)	Northern parts of sections 3-a and 4-a	High	Early spring to late fall	Early spring, 15	Practically any type, except sand	Better for hay than pasture; inclined to be stemmy
Tall oatgrass (*Arrhenatherum elatius*)	Sections 1-b and 5-a	Medium	Early spring to late fall	Early fall, 20–25	Practically any type, except sand	Better in hay mixtures than for pasture; stemmy; used most for pasture in section 5-a
Timothy (*Phleum pratense*)	Region 1 and section 5-a; also sections 3-a and 4-a where moisture is sufficient	High	Early spring to late fall	Early fall (or early spring), 12–15	Practically any type, except sand	Comes quickly and furnishes much pasturage at first but is not permanent

* The region and section numbers refer to those in Fig. 7

† Specifications of soil types in this and the following tables are necessarily very general because of space limitations.

Tropical grasses have a greater capacity to stand heat and utilize intense radiation than do temperate species. Under these conditions tropical grasses have been established at land application sites and utilize maximal amounts of water and nutrients. Because they are sensitive to cold, however, they grow only during warm seasons and cannot even be successfully maintained further north than the Carolinas.

Techniques Exist for Extending Active Growing Seasons

In the south, the growth of cool season crops may allow plant wastewater renovation throughout the year; in the north periods exist when no crops will grow actively. Nevertheless, the season of active growth can be extended through crop selection (Figure 8). Where the length of growing season permits, double cropping of short season varieties of annual crops will generally rival the nutrient uptake of perennial crops, and invariably surpasses that of long season annuals. Fall seeded small grains grow later in the fall and earlier in the spring than pasture and meadow crops. Rye is the most cold and water tolerant of the small grains. Fall seeded small grains are usually seeded after the harvest of an intertilled crop such as beans or early corn. They may be successfully seeded after a sod if the sod is plowed after the first cutting. No tillage techniques may extend the options available to the farm manager on a land application site. The Army Crops of Engineers (1972) selected a minimum tillage corn-rye cropping system for illustrative purposes in their attempt to integrate crop production with wastewater disposal in northern Illinois. In this scheme corn was grown each year, rye was areally broadcast 1-2 weeks before corn harvest. Rye forage was harvested in mid November and was killed with a contact herbicide prior to no-till corn planting in the spring. The Corps determined that 500 lbN/acre/year could be applied without degrading groundwater quality (Table 15).

The growth of cool season crops in the south may allow plant wastewater renovation throughout the year.

Double cropping of short season annuals may rival the nutrient uptake of perennials in temperate areas. No tillage techniques also provide for uninterrupted crop rotations.

In general, it is important that the land application site designer consult the local agricultural extension office, state college, or department of agriculture office for crop varieties and species suited to the area and the wastewater application situation.

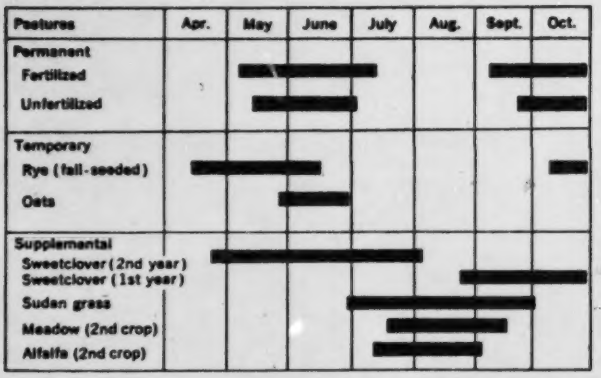

FIG. 8 Combined use of permanent, temporary, and supplemental pastures designed to provide adequate grazing throughout the season. (USDA, 1939)

Table 15. Fate of N Applied to Corn-Rye Rotation (Army Corps of Engineers, 1972)

Harvest Removal	Pounds of N
Corn grain	195
Rye forage	85
Corn stover (partially removed with rye forage)	20
Volatilization and Denitrification*	150
Tolerable Leaching Losses	50
TOTAL	500

* Thought to occur mainly during the first 30 days of corn growing season.

Crop Tolerances to Nutrients and Salts

When additions of elements in excess quantities are made, the natural functionings of plants may be disrupted. Such effects may be apparent from the reduced growth, delayed maturity, lodging, or reduced quality of crops. There are many mechanisms which can cause these effects. Reduced growth may be due to high total salt concentrations or to high concentrations of a specific ion. Reduced quality may vary all the way from a lack of proper color in fruit to actual toxicities in animals consuming the plants.

Excess nutrient problems differ from problems due to high concentration of total salts or trace elements, because large amounts of these nutrients are needed for normal crop growth. N, P, and K are added routinely by farmers. When irrigating with wastewater, however, the farmer loses a degree of control over the timing and the amount of fertilizer applied.

Phosphorus

Excessive phosphorus may be toxic to plants by inducing deficiencies of Cu, Zn, Fe or Mn. Hinesly et al., (1974) added excessive amounts of liquid digested sludge to several crops, and observed phosphorus toxicity in soybeans during one season. In this experiment, much more sludge was added than would be recommended on the basis of N, P, or potentially toxic element loadings. It is unlikely that phosphorus toxicity would result from moderate applications of wastewaters or sludges.

It is unlikely that phosphorus toxicity would result from moderate applications of wastewaters or sludges.

Potassium

Potassium is generally not toxic to plants or plant consumers although in combination with high nitrate levels it has been associated with reduced magnesium

uptake in forages and subsequent deficiencies in lactating cows and sheep (grass tetany). Potassium is generally low in sludges and present in moderate amounts in wastewaters and effluents. Potassium should not cause toxicity problems although deficiency problems may arise.

Nitrogen

Most of the problems associated with excess and untimely fertilizer application center around nitrogen. Crop logging, or analyzing plant samples to determine nutritional status, has resulted in correlations between high nitrogen levels and a variety of problems. Abundant nitrogen and water results in lush growth. This can result in lodging of small grains and buckwheat (inability of the soft stems to support the oversized, heavy seeds), excessive foliage growth of potatoes and cotton at the expense of tubers and fruits, decreased sugar content of sugar beets, and increased fruit rot and decreased vitamin C, due to shading, in melons, squash and tomatoes.

Excess nitrogen can be damaging to several types of crops. These include small grains, tubers, cotton, sugar beets, melons, squash and tomatoes.

Excess nitrates in forages is a special problem. Nitrate accumulation in plant tissues varies with plant type, climatic conditions, and fertilization. Certain weeds (i.e., pigweed) accumulate nitrate up to 1-1.5 percent of their dry weight. Under conditions with slow growth (drought, cold, or extended periods of cool cloudy weather) corn, sorghum, and succulent annual grasses may accumulate abnormally high concentrations of nitrate. Applications of high-nitrate-containing wastewaters a short time prior to harvest may increase nitrate levels in crops. High nitrate forages are a problem in two ways: 1) Nitrogen oxide gases that can be deadly to humans and farm animals in enclosed areas can be formed immediately after ensiling high nitrate forages, and 2) Nitrate may be converted to nitrite in alkaline digestive tracts (i.e., within ruminants and human infants)

High nitrates in forage crops can produce nitrous oxide upon being ensiled or cause cyanosis in ruminants.

which may react with hemoglobin and reduce its capacity to transport oxygen, resulting in methemoglobinemia or cyanosis. At nitrate levels higher than 0.1 percent of animal body weight there is a 50 percent fatality rate (see Module 15, "Nitrogen Considerations").

Other miscellaneous problems have been reported. Tall fescue, one of the most palatable grasses well adapted to moist conditions, has been observed to cause fatty tumors on the intestines of cattle ("fat necrosis") when fertilized with heavy rates of manure (Hart, 1974). The milling and baking qualities of wheat grain produced with wastewater have been found to be lower than the qualities of grain grown with well water and commercial inorganic fertilizers (Day, 1973).

At Bakersfield, California, management factors which have been employed to counteract the effect of excessive and untimely applications of nitrogen on cotton include: 1) Thin cotton more than usual, 2) Stress the plants between irrigation periods to stimulate fruitive growth and 3) Blend effluent with well water to reduce the total N concentration (Crites, 1974).

Modifications to counteract the effect of excessive and untimely applications of nitrogen have included thinning the crops, stressing them between irrigation periods and diluting the wastewater.

Salts

Besides excess amounts of macro-nutrients, the most general and most extensively studied reason for reduced crop growth is referred to as "salts". "Total Salts" means essentially the same thing as "total dissolved solids", a commonly measured characteristic of wastewaters and effluents. Studies have shown that from 247-421 mg/l of total dissolved solids (average 300 mg/l) is added to water by one municipal use (Baier and Fryer, 1973). When a solid dissolves in water it generally breaks apart into positively and negatively

charged parts or ions. The mobility of an ion in solution depends on its charge, its mass, its size and shape, as well as on temperature and other factors. Because they carry charges and are mobile, ions in solution will conduct electricity and are often measured as electrical conductivity (EC) in water and wastewater.

Salt problems have been investigated in relation to experience gained in arid areas under irrigation, in greenhouse culture, and in the reclamation of land from the sea. In spite of the variation in ionic balances which might be presumed to exist between these different situations, salts, as measured by electrical conductivity, have been consistently correlated with yield reductions.

Excess salts have been correlated with yield reductions, mainly in arid areas.

Regardless of the mechanism, accumulation of salts in arid soils has been a recognized problem for some time, and a body of practical knowledge has been accumulated. "Salts" are generally measured as the conductivity of a soil water extract. Electrical conductance is expressed in mhos which are reciprocal ohms. Electrical conductivity has the dimensions mhos/cm. In practice millimhos turn out to be a convenient size unit and results are usually expressed as mmhos/cm or EC x 10^3.

As with tolerance to waterlogging, crops vary in their tolerance to excess salts in the soil solution (Table 16), and tolerances vary with stage of growth. In Table 16 it should be noted that Reed canary grass, while tolerant to flooding, drought and scald, and while

Crops differ in their tolerance to excess salts. Tolerance also can depend on the stage of growth of the crops.

Table 16. Relative Tolerances of Field and Forage Crops To Salt or Electrical Conductivity[a]

Tolerant (partial listing)	Semitolerant (partial listing)	Sensitive (complete listing)
Barley	Alfalfa	Alsike clover
Bermuda grass	Corn (field)	Burnet
Birdsfoot trefoil	Flax	Field beans
Canada wildrye	Oats	Ladino clover
Cotton	Orchard grass	Meadow foxtail
Rape	Reed canary grass	Red clover
Rescue grass	Rice	White dutch clover
Rhodes grass	Rye	
Sugar beet	Sorghum (grain)	
	Sudan grass	
	Tall fescue	

[a] Tolerant - 10,000-18,000 umhos/cm;
Semitolerant - 4,000-12,000 umhos/cm;
Sensitive - 2,000-4,000 umhos/cm.

Source: Pound and Crites, 1973

efficient in taking up large amounts of nutrients, is only moderately tolerant of salts. Barley, which will not tolerate waterlogging, is very tolerant of salts. Day (1974), however, noted that barley was found to be more sensitive to the constituents in wastewater than was oats or wheat.

Criteria for Salt Content of Irrigation Water Have Been Developed

Unless diluted by rain, salinity of the soil solution will at least equal that in irrigation waters. Due to evaporation, soil solution concentrations in arid areas generally exceed those of applied waters. Based on experience in a variety of climatic and

Soil solution concentrations of salts are generally higher than the concentration in applied wastewater.

drainage situations, criteria have been developed which should be directly applicable to the evaluation of effluents and wastewaters as sources of irrigation waters. Table 17 summarizes those of the US Salinity Laboratory. Based on U.S. criteria, an effluent containing 500-1500 ppm TDS would be classified as "high-salinity water" not suitable for use in arid areas on soils with restricted drainage. In light of experience with use of very low quality irrigation water, new criteria have been proposed by workers in Algeria (Table 18). These criteria, based on soil type as well as plant tolerance, assume ideal irrigation conditions (permeable soil and good drainage) and so may have applicability on intensively managed land application sites. It is clear from Table 18 that the excellent drainage characteristics of coarse soils greatly outweigh the relative dilution advantage of clay soils in avoiding toxic salt concentrations. When a significant fraction of the applied wastewater moves through the soil as percolation, salt buildup may not be a problem even in arid areas unless the wastewater TDS is exceptionally high and sensitive crops are grown.

With good drainage and management, crops can be irrigated with high salinity wastewater.

In addition to the effect of total salts on crop growth, high concentrations of certain elements have been recognized to be particularly harmful. Sodium is perhaps the most critical ion to be considered in waters containing appreciable amounts of TDS. Na is critical because it affects plant growth directly, and indirectly through its undesirable effect on soil structure and permeability. These affects are summarized in Table 19, wherein sodium concentration is expressed in terms of exchangeable-sodium percentage (ESP). This is a measure

Excessive sodium affects both plant growth and soil structure. Plants in the most tolerant to sodium group can be grown when the ESP is over 60.

Table 17. US Salinity Laboratory's grouping of irrigation water

Classification of water	Electrical conductivity in umhos/cm at 25°C(EC)	Salt concentration in g/l (approximate)
C1 Low salinity water can be used for irrigation with most crops on most soils, with little likelihood that a salimity problem will develop. Some leaching is required, but this occurs under normal irrigation practices, except in soils of extremely low permeability.	$0 < EC \leq 250$	< 0.2
C2 Medium-salinity water can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most instances without special practices for salinity control.	$250 < EC \leq 750$	0.2-0.5
C3 High salinity water cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.	$750 < EC \leq 2250$	0.5-1.5
C4 Very high salinity water is not suitable for irrigation under ordinary conditions but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt tolerant crops should be selected.	$2250 < EC \leq 5000$	1.5-3

Source: FAO (1973)

Table 18. Upper limits of electrical conductivity, in micromhos, of irrigation water for three groups of plants and five soil groups

Soil Textures	Plant tolerance groups					
	I (Low)	II (Moderate)	III (High)			
			Dutt	Horticultural	Forage	Field Crops
Sandy	2500	6500	15000-20000	8000	12000	10000
Loamy sand	1600	4000	6000-10000	4500	7000	6000
Loamy	1000	3000	8000	3500	5000	4500
Loamy clay	800	2000	6000	2400	--	3500
Clay	400	1000	3000	1800	1800	1600

Group I = Electrical conductivity of soils saturation extract <4000 umhos/cm
Group II = Electrical conductivity of soils saturation extract 4000 to 10000
Group III = Electrical conductivity of soils saturation extract > 10000

Source: FAO (1973)

Table 19. Tolerance of various crops to exchangeable-sodium percentage (ESP) under nonsaline conditions

Tolerance to ESP and range at which affected	Crop	Growth response under field conditions
Extremely sensitive (ESP = 2-10)	Deciduous fruits Nuts Citrus Avocado	Sodium toxicity symptoms even at low ESP values
Sensitive (ESP = 10-20)	Beans	Stunted growth at low ESP values even though the physical condition of the soil may be good
Moderately tolerant (ESP = 20-40)	Clover Oats Tall fescue Rice Dallisgrass	Stunted growth due to both nutritional factors and adverse soil conditions
Tolerant (ESP = 40-60)	Wheat Cotton Alfalfa Barley Tomatoes Beets	Stunted growth usually due to adverse physical condition of soil
Most tolerant (ESP = more than 60)	Crested and Fairway wheatgrass Tall wheatgrass Rhodes grass	Stunted growth usually due to adverse physical condition of soil

Source: Bernstein (1974)

of the percentage of active cation exchange sites in the soil which are occupied by Na^+ ions. For instance, when 15% of the exchange complex is occupied by sodium, the exchangeable sodium percentage equals 15.

Boron has been identified as a problem in some irrigated areas, and is one of the most troublesome elements discussed in Module 11, "Potentially Toxic Elements". Information on the crop tolerance to boron is reproduced in Table 20. In soils where B is already high, careful analysis of wastewaters should be made, as concentrations are often high enough to cause problems. Boron concentrations may increase in the future if borates are increasingly substituted for phsophates in detergents (Dowdy, et al., 1976). Borates, like nitrates, move readily through soils with percolating waters.

Excessive boron is phytotoxic. Borates also leach readily.

Chloride is generally not recognized as a problem in field crop production, and Eaton (1971) states that anions are generally harmless. Its effects interact with those of total salts and Na. When chlorinated effluents are applied to cropland the largest effect may be an increased lime requirement (Chaney, 1973).

Table 20. Crop tolerance limits for boron in saturation extracts of soil. For each group, tolerant, semitolerant, and sensitive, the range of tolerable boron concentration is indicated. Tolerance decreases in descending order in each column

Tolerant	Semitolerant	Sensitive
Sugarbeet	Potato	Pecan
Alfalfa	Cotton	Walnut
Turnip	Barley	Plum
	Wheat	Pear
	Corn	Apple
	Milo	Grape
	Oat	Cherry
		Peach
		Orange
2.0 ppm of boron	1.0 ppm of boron	0.3 ppm of boron

Source: Bernstein (1974)

Practical Considerations

Thus far in this module, the requirements and tolerance of a variety of crops have been discussed with reference to the conditions which are likely to prevail at a land application site: high hydraulic loading with water high in nutrients, salts and potentially toxic trace elements. In this section a variety of miscellaneous observations are made, which may be of some benefit in anticipating returns and avoiding unexpected problems.

Costs

The cost effectiveness of a cropping system depends upon many things, not the least of which is the manager's ability to market his crops. Table 21 and 22 are an indicator of potential value of a cropping operation.

In Tables 21 and 22 figures were taken appropriate to the most productive soils receiving recommended management. This results in optimum yields (Table 22) and when these are combined with favorable prices, considerable profit margin may theoretically be realized. If unfavorable price relationships exist at harvest time then the situation may be dramatically changed. If wheat brought only $1.50/bu then a yield of over 60 bu/acre would be required just to break even. The costs in Table 21 and 22 do not include any charges for land costs or taxes or interest on investment. The values assigned to haylage and corn silage by Knoblauch and Milligan (1977) represent their value to a farmer feeding dairy cattle. These products are difficult to transport long distances and cannot be readily stored once removed from the silo. If animals are fed ensilage, pasture, or other crops as part of the land application system, most of the nutrients contained in the crop would have to be recycled back to the land in the form of animal manures. If harvested

When well managed and with a favorable market price, crops can yield a favorable profit margin. Low prices can result in a loss.

as hay, forage crops may more easily be sold off the farm. For such sale, however, quality is important and the type of hay which is in greatest demand (probably alfalfa) may reasonably influence crop selection. Making hay, however, has inherent risks as it is not possible to control the weather. In fact, on land application sites where soils may never become hot and dry, the curing of hay would be relatively slow. The quality of the hay harvested might not always be the best, but it could still be profitable in areas where demand is strong.

Crop Management

In evaluating crop relations for a land application site, all of the subjects previously addressed in this module should receive consideration. When applied to the best agricultural soils, wastes will be of value for their N, P and water content. As shown in Table 21, savings in fertilizer may be substantial. Practices such as irrigation and drainage represent additional costs to the farmer but increase the farmer's control over the environment surrounding his crops. In some locations, improved drainage may confer benefits comparable to that of the supplied fertilizer. With good drainage, additional crops become adapted to a site, and all crops may be planted and harvested earlier. In some locations cropping is limited or impossible without irrigation waters. In humid areas on deep soils a benefit from irrigation would be realized in all but the ideal crop growing years. Also the availability of irrigation waters would act as insurance protecting a farmer's investment in seed and tillage and this could do much toward stabilizing the agriculture in an area. Available water would be especially beneficial when starting small seeded forage species. Seeding a forage mixture in the fall following wheat harvest is a risky practice if adequate moisture is not assured.

Wastewater and sludge has considerable fertilizer value. Improved drainage and irrigation capability can allow a wider variety of crops to be planted, the ground can be worked earlier and harvest can take place earlier.

Table 21. New York State Production Costs - 1977

	Corn	Alfalfa [4]	Wheat
Tillage[2]			
plow @ $10/ac	$25.00	$6.25	$25.00
disc @ $ 6/ac	(10.00)	(2.50)	(10.00)
harrow @ $3/ac	(3.00)	(1.00)	(3.00)
Planting[2] @ $5/ac	5.00		
Drill[2] @ $5/ac		1.25	5.00
Apply Fertilizer, Lime or pesticides[2] @ $3/ac	3.00	1.50	3.00
Cultivate[2] @ $5/ac	5.00		
SUBTOTAL	($38.00)	($9.00)	($33.00)
Seed[1]	(.3 bu) 13.80	(12 lbs) 4.25	(2.3 bu) 14.50
Fertilizer[1]			
N @ $.18/lb	(130 N) 23.40		(60 N) 10.80
P_2O_5 @ $.19/lb	(60 P_2O_5) 11.40	(75 P_2O_5) 14.25	(60 P_2O_5) 11.40
K_2O @ $.10/lb	(60 K_2O) 6.00	(100 K_2O) 10.00	(40 K_2O) 4.00
Lime, cover crop, other[1]	7.00	3.00	3.00
Herbicide	6.85	2.00	
Pesticides	12.30[3]		
SUBTOTAL	($80.75)	($33.50)	($43.70)
Harvest			
combine corn	20.00[2]		combine small grain 15.00[2]
dry corn	21.60[1]	mow, bale haul and store hay 100.00[5]	
sell corn	6.80[1]		sell wheat 5.50[1]
SUBTOTAL	($48.40)		($20.50)
Total Dry Shell Corn	$167.15	Total hay $142.50	Total wheat $97.20
Field Chop Corn	(30.00)[2]	Chop Haylage (30.00)[2]	
Total Haylage	$148.75	Total Haylage $72.50	

[1] From Knoblauch and Milligan, 1977

[2] From Knoblauch and Snyder, 1977

[3] Third year and thereafter of cont. corn-spray for rootworm @ $12.30/acre

[4] Tillage and seeding costs are reported as 1/4 of the actual cost because the stand is assumed to be productive for 4 years without renewal.

[5] based on yield of 5 ton/acre at a cost of $.50/50 lb bale (from ref. 2)

Table 22. N.Y.S. Production Costs and Returns - 1977

Crop	Cost[1]	Return[2]	Margin/acre
Dry shell corn	$167.15/acre	120 bu/acre x $2.50/bu = $300/acre	$132.85
Corn ensilage	$148.75/acre	20 tons/acre x $17.00/ton = $340/acre	$191.25
Hay	$142.50	5 tons/acre x $70.00/ton = $350/acre	$207.20
Haylage	$ 72.50	15.6 tons x $21.15/ton = $330/acre	$257.20
Wheat	$ 97.20	60 bu x $3.00/bu = $180/acre	$ 82.80

[1] From Table 21

[2] Based on estimates as indicated.

In selecting a crop the question of the actual physical management of the wastes is very important. Foliar applications of sludge to standing hay may do more to contaminate the crop than any amount of waste additions made directly to the soil. Chaney et al. (1976) reported that a considerable fraction of the elements applied when sludge was spread onto a freshly cut tall fescue meadow were not washed off the plants by

Foliar applications of sludge may contaminate forage. The residue may not be washed off by rainwater.

subsequent rains although their concentrations were diluted by subsequent growth. Applications of sludge on actively growing forage crops, while being desirable in terms of N and P renovation, may result in contaminated forage if the sludge is allowed to dry and form a crust on plant leaves. This could greatly reduce the value of harvested hay or haylage. Analysis of applied wastes, field observations, and analysis of plant samples are necessary for intelligent management. Where one waste might result in crops with elevated levels of cadmium, another waste might not even correct boron deficiencies.

Crop Establishment

Once a crop has been selected it must still be managed correctly. Knowledge of how to do this is shared among farmers throughout the country and agriculturalists at many agencies and land grant institutions. While reed canary grass may be chosen because of its high nutrient uptake and water tolerance, it should also be recognized that reed canary grass loses palatability quickly as it approaches maturity and must be cut 3 times per season for maximum production. Reed canary grass is also slow to establish. In one overland flow experiment at Penn State, where reed canary was sown with Italian ryegrass, the quickly germinating ryegrass completely dominated the first year's forage growth (Butler, et al., 1974). Reed canary grass is often sown in other grasses only in a few widely separated rows with the intent that it will spread out and dominate over time.

If an annual crop is selected then in most cases a conventional seed bed will be prepared. In most soils planting must be delayed until the soils are dry enough and warm enough to avoid compaction and ensure rapid germination. Because sludges may inhibit germination,

Agricultural factors may necessitate cessation of irrigation for a period of time.

they may have to be spread some time ahead of tillage operations. To allow for the drying and warming of the soil, wastewater application may have to be withheld until weather conditions allow planting and germination.

An important aspect of the establishment of any crop is weed control. Weeds are controlled by a combination of tillage and herbicide application. Any successful tillage operation requires that the soil be dry enough at a 6 inch depth to avoid compaction and thus, like making hay, will require suspension of wastewater applications for variable periods, depending on weather. It would seem, under these circumstances, that herbicide would be an easier way to control weeds. Herbicide activity, however, may be significantly reduced by leaching a soil with large volumes of wastewater. Degradation by a large population of soil microorganisms maintained in moist, fertile soils can also reduce herbicide activity. Since the activity of the various herbcides may be differentially affected by the moist conditions, it will be necessary to consult an expert in this area.

Herbicides may be affected by conditions at a land treatment site.

Crop Selection - Conclusion

This module is intended to serve as a non-technical introduction to many of the complex factors which have been recognized by crop scientists. It is not intended to provide complete instruction in farm management. It has attempted to supplement information contained in other modules. In any applied situation, an expert will no doubt be employed to manage farming operations, including crop selection, at a land application site. The information in this module is intended to provide a basis for communication between agricultural specialists and planners. It is hoped that it will provide some feeling for the kind of knowledge which is available, and the kind of problems which may be anticipated and avoided at preliminary design stages of a land treatment system involving crop production.

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CROP SELELCTION AND MANAGEMENT ALTERNATIVES

Objectives

Upon completion of this module, the participant should be able to:

1. Figure the amount of irrigation necessary to satisfy crop needs for a particular crop.
2. Indicate the frequency of irrigation to satisfy crop needs.
3. Indicate which agricultural crops utilize the highest amount of nutrients.
4. Indicate an acceptable level of dissolved solids in irrigation water.
5. Indicate methods of extending the active growing season.

RETURN TO LESSON PACKAGE

Script to Accompany the A-T

CROP SELECTION AND MANAGEMENT ALTERNATIVES

Module 20

January, 1978

CROP SELECTION AND MANAGEMENT ALTERNATIVES

(Slide 1) Crops contribute to a land application system in several ways and, therefore, should be carefully selected and managed to maximize the contribution they make to the total land treatment scheme. This module concerns the selection and management of the crops at a land treatment site. The objectives for this module are in the envelope that is with the module box. Turn off the tape and study the objectives (Slide 2). You may keep the objectives for reference during this lesson.

Slide 3 indicates the contribution which an agricultural crop can make to the total land treatment system. Crops are essential for an overland flow system, very important for an irrigation system, and less important for a rapid infiltration system of land application. Although, as Slide 3 indicates, a crop on a land application site has many advantages -- there is a concommitant increase in the management and labor requirements for the growing of a successful crop, that must be understood and considered.

Slide 4 enumerates some of the criteria which should be considered in selecting vegetative cover for a land application site. Before this selection occurs, however, it is important to conduct a thorough analysis of the waste that is going to be applied to the selected crop. This analysis should consist of an assessment of the usual wastewater characteristics plus the assessment that is usually conducted to analyze irrigation waters. Slide 5 indicates the constituents that are usually determined for irrigation waters. An analysis of the soil for pH, potentially toxic elements, native concentrations of nitrogen and phosphorus as well as CEC and exchangeable cations, especially potassium, should also be conducted. A deficiency of these cations can lead to decreased crop yields.

Almost all crops can be irrigated with untreated wastewater. Slide 6 indicates the crops that are grown in the world's largest land treatment system - the system serving Mexico City. Although the wastewater in this system is technically untreated, it does travel 70 kilometers to the irrigation sites in an open ditch.

This can result in the same treatment as would occur in an oxidation pond. Most of the crops on this list would not be irrigated with raw wastewater in the United States because of the potential health hazard to people and animals. This hazard may result from viable pathogens on the crop

which would pose a threat to those working in the field and to people and animals ingesting the crop before complete cooking. Many of the crops on this list could not, legally, be irrigated even with secondary treated effluent. For further information on state regulations see Module 16, "Legal Aspects" (Slide 7).

Slide 8 indicates some of the crops irrigated with wastewater in the United States, and the size of the land treatment systems. Notice that the flows range from less than 150,000 gallons/day to 9 million gallons/day. It should be evident from this and the table in Slide 6 that practically any crop adapted to the prevailing temperature regime could be grown with wastewater irrigation. This module will discuss the tradeoffs which must be made in selecting and managing crops irrigated with wastewater. The module will not result in the land treatment system designer becoming an agricultural expert thus consultation with a qualified agronomist will still be essential.

(Slide 9) It is well known that management, climate, and plant variety all influence crop yield. Even in humid areas, yield is limited in most years by insufficient water. Slide 10 indicates some yield data from a study in Pennsylvania. The greatest increase in yield was with one inch of irrigation with wastewater. The differences between 1 and 2 inches per week treatments were not as marked in this particular study. Other studies, however, have found marked differences with an increase in application rate.

Crops differ in their rooting habits, and thus the drainage characteristics of the different types of soil can influence their responses to irrigation. Slide 11 illustrates the different rooting habits of various types of crops. Some of these crops, such as spinach would not be used in irrigation with wastewater but are included for illustrative purposes. Spinach has a shallow rooting habit, sugar beet an intermediate, and alfalfa a deep rooting habit. Shallow rooted plants thrive with frequent irrigations, although they will not necessarily stand water logging. In mixed stands the requirements of the most shallow rooted species dictates the required frequency of irrigations. In a mixed meadow stand it is usually the clovers that are the most shallow rooted. Deep rooted plants take up a similar amount of water as shallow rooted species when moisture is adequate.

Slide 12 illustrates a production function for alfalfa. This is a plot of crop yield versus water application and is the type of information useful for planning irrigation water requirements. These functions are empirical and must be generated in the area to which they will apply and for the specific crop. State extension services or agricultural college personnel can provide these curves for locally grown crops. Increasing yield is associated with increasing transpiration. The point on this curve (Slide 12) at which yield levels off indicates that maximum evapotranspiration is approaching potential evapotranspiration. This is the point at which excess water begins to percolate. That is not to say, that thirty to forty inches of wastewater can be applied to alfalfa all at one time without percolation. This irrigation water must be applied in small amounts throughout the growing season to satisfy the season long transpiration demand. The reduced yield with increasing water application could be due to poor aeration or a reduced supply of available nitrogen. Wastewater may contain adequate available nitrogen to avoid possible reduced yield.

Transpiration from crops and evaporation from the surface soil depend upon available moisture and available energy. Slide 13 indicates the nature of the water potential gradient which exists between soils, plants, and air. As the available water in the soil decreases the water potential gradient is lessened somewhat since the soil moisture is held at 10 to 20 bars. This does not, however, affect the overall moisture potential. Evapotranspiration is decreased due to decreased capillary flow as the soil surface dries. The degree to which a plant may satisfy a high transpiration demand depends upon the size and density of its root system. Anything which restricts the depth or vigor of root penetration may restrict transpiration. Heavy wastewater application early in the growing season as well as poor soil drainage can restrict root development and thereby lower potential transpiration.

Slide 14 indicates the variables that affect evapotranspiration. Albedo and turbulence are both influenced by the type of crop and the method of planting. Open row crops can increase surface area, turbulence and mixing and hence evapotranspiration above that even of a wet surface.

Evapotranspiration can be determined by the methods indicated in Slide 15. The climatological methods estimate the potential ET that would

be produced by the prevailing climate if available moisture were not limiting, which is usually the case at a land treatment site. The temperature correlations, such as those developed by Blaney-Criddle and Thornthwaite are not good estimates of short term water demand but are suitable for the long term. Their advantage lies in their simplicity and the availability of temperature records (Slide 16). The other methods are more complex, but yield more accurate short and long term information. A local college of agriculture can provide the information necessary to use these formulae. In land application systems (Slide 17) accurate estimates of evapotranspiration along with known amounts of precipitation and applied wastewater that actually reaches the soil would allow a good estimate of the amount of water percolating through the root zone. This gives a basis for determining the concentration of potential pollutants that leach through the system.

For maximum yield plants require a specific amount of moisture for transpiration every day. This amount depends upon the type of plant and the depth of the roots, the stage of growth and the climate. Slide 18 indicates the peak period water demand for several crops that are likely to be grown at a land treatment site. Slide 18 also indicates the soil moisture tension at which a crop should be irrigated for maximum yield. Thus potatoes require 0.2 inches of water per day from about 18 inches of soil and should be irrigated when the soil moisture tension is about -0.4 bars. Using the information in Slide 19 allows a reasonable approximation of the available water held by a given soil type at any given soil moisture tension. A moderately coarse sandy loam soil, therefore, will hold about 1.5 inches of water per foot. The utility of this information can be illustrated by the example in Slide 20. The potatoes that were mentioned before need 0.2 in/day of water. They must obtain this water from 18 inches of soil, and should be irrigated when the soil moisture tension reaches -0.4 bars. In the depth that the potato roots explore the soil contains about 2 1/4 inches of water, at field capacity, and would yield 50% of this water before the moisture tension reaches -0.4 bars. This information can be obtained from Slide 19. It would take the potatoes little more than five days to use that amount of moisture. Therefore, the potatoes should be irrigated more often than once a week for maximum yield no matter how much water was applied, since the soil drains down to field capacity. Precipitation, of course, must be taken into account. The potatoes in the example, however, ought to have 1.4 inches

of water in the root zone every week. With different soils and in different areas this requirement would differ. It would be advisable to consult an agronomist for the calculations in your area. These calculations, also do not provide for leaching of water but can help the site designer plan for enough water leaching to maintain groundwater quality. They also indicate that for maximum yield, crops can utilize irrigation water even in the humid zones.

Up to this point, we have been discussing water requirements of crops. In general, a land application system will not have a problem meeting the required amount of water for successful crops. It is just as important, however, to not damage the crop by applying too much water. Adequate drainage, either natural or artificial, assures that flooding of the root zone will not result in crop losses. Slide 21 indicates the benefits of the removal of excess water from a land treatment site.

Respiration of both plant roots and aerobic microorganisms depends upon an adequate supply of oxygen in the root zone. Slide 22 indicates the diffusion coefficient of oxygen in air and in water. The diffusion coefficient of oxygen is even slower in saturated soil. If flooded, the roots and microorganisms rapidly deplete the available oxygen, with high temperature accelerating this process. This may directly affect crops by reducing root growth, water and nutrient adsorption. Slide 23 indicates the oxygen diffusion ratio measured at various times and depths after furrow irrigation on a clay loam soil. The roots of many crops will not grow with oxygen diffusion rates of less than 0.20 ug/cm^2/min or 12 lbs/acre/day. Notice that four days after irrigation the oxygen diffusion ratio was still inadequate below the thirty centimeter level. The results were not significantly different using spray irrigation. In other experiments the rate of recovery of the ODR has been dependent upon crop rotation and cultural practices. The natural porosity of the soil is probably the most important factor, however, influencing soil aeration. In any case, excessive application of wastewater can irretrievably damage a crop by preventing adequate aeration.

There are a multitude of factors influencing the affect of flooding on crops. As shown in Slide 23 these factors do not act on each crop in the same way or at the same time. Complete information on the response of

each crop to these variables is not even recorded. A local agricultural college can provide the available information for specific crops and areas. Slide 24 provides somewhat of a generalization of the flooding tolerances of different types of crops. It seems that the most susceptible period for a crop to damage from flooding is when it approaches flowering. Rice, of course, is the crop most adapted to flooded conditions. Certain species of grasses are also quite tolerant. Tobacco and beans are among the less tolerant crops.

Under irrigation, favorable moisture relations can increase the potential for crop disease and insect problems (Slide 25). These vary with the crop and the climate. A local agricultural extension agent or state agricultural college or USDA representative can advise the designer on insect and disease control for the particular site, local conditions and specific crop.

One of the primary objectives of land application is the removal of soluble nitrogen and phosphorus (Slide 26). If the vegetation grown at a wastewater irrigation site is not removed, then nutrients will recycle within the biomass, accumulate, and eventually leak to the environment either through groundwater or surface waters (Slide 27). Thus, in order for crops to be an effective waste sink, they must be harvested and disposed of either by selling the crop, feeding it to animals, letting animals graze on it, or some other method. The removal of macro and micronutrients allows higher nutrient application rates without environmental degradation, and can be regarded as prolonging the effective life of a site. If nutrients are applied only to meet crop requirements and losses, then the site should remain effective indefinitely (Slide 28).

Slide 29 indicates some values reported for yields and nutrient uptake of agronomic crops. Notice that when only the grain is harvested, the harvest of nutrients is relatively low. Slide 30 indicates the nutrients in the total above ground portion of the different crops. The figures in parentheses indicate the amount of nutrient in the grain only. The difference between the two figures is the amount of nutrient removal gained if harvest includes the crop residue. Notice also, that the uptake of phosphorus is 1/5 to 1/10 the uptake of nitrogen. Since nitrogen, however, is usually the limiting factor in applying wastes to the land, we will use the nitrogen figures in this table to relate uptake to application.

Slide 31 indicates that typical untreated sewage contains about 40 mg/l nitrogen. The table in that slide indicates the amount of untreated effluent that would have to be added to a site to just satisfy the crop needs. Alfalfa takes up the most nitrogen with reed canarygrass being a close second. For many years designers of land treatment sites shied away from planting alfalfa because it produces organic nitrogen from atmospheric nitrogen, as do all leguminous plants. There is much evidence, however, that when provided with nitrogen, such as in effluent, a legume will use the provided nitrogen rather than fixing atmospheric nitrogen. These figures in the table only indicate the amount of effluent that will satisfy the crop requirements for nutrients. Module 15, "Nitrogen Considerations" indicates other factors that increase the amount of nitrogen that can be applied to a site safely (Slide 32). The amount of phosphorus added to a site, when using nitrogen as the limiting factor will provide more than enough for crop needs, but as discussed in Module 19, "Phosphorus Considerations", this amount will not usually be a problem. Finally, at almost all application rates for irrigation or overland flow or municipal wastewater and sludges, supplemental potassium fertilizer will have to be added for adequate crop growth.

There is a slight danger, when applying large amounts of waste to the land that excessive macronutrients, like nitrogen and phosphorus, or micronutrients like zinc will be added to a site (Slide 33). Module 11, "Potentially Toxic Elements", discusses the dangers of excessive amounts of these entering the food chain, and these will not be discussed here in detail. Different crops react differently to various concentrations of potentially toxic elements, and few generalizations can be drawn. Slide 34 indicates one suggestion for the total amount of metals that can be added to the soil. This amount is related to the cation exchange capacity of the site. These proposed amounts would allow the safe application of domestic wastewater for the design lifetime of almost all sites. Heavily contaminated industrial wastewaters, however, may exceed these limits in less than the typical site lifetime. Plants demonstrate varying degrees of selectivity in the active uptake and translocations of these potentially toxic elements. Cadmium, for example, usually has a much lower concentration in the fruits and grain of a crop, than in other parts of the plant.

Excess nitrogen can cause crop problems. Excess nitrogen and water results in lush growth of the seeds of some grains (Slide 35). This can result in a condition known as lodging, in which the stem cannot support the seeds and the stems either bend over or break, making grain harvest very difficult. Excessive foliage growth at the expense of tubers and fruits has been reportedly caused by excessive nitrogen in potatoes and cotton.

High nitrate forages can be a problem in two ways: Oxides of nitrogen that can be deadly to humans and farm animals can be formed immediately upon ensiling high nitrate forage (Slide 36). Nitrate may be converted to nitrite in alkaline digestive tracts, such as within the rumen of farm animals. This nitrite, in significant quantities, can be fatal. Nitrates, however, should not have a long residence time in crops before they are converted to organic nitrogen. Therefore, it might be wise to not irrigate with high nitrate wastewater for a brief period before harvest, or to dilute the wastewater.

As stated previously in this module, excessive phosphorus and potassium will not be a problem at a land treatment site. Agricultural crops fertilized with wastewater may even need potassium supplements (Slide 37).

The most general and most extensively studied reason for reduced crop growth is referred to as salts (Slide 38), which is the same as total dissolved solids. Excessive salts have been responsible for the ruination of thousands of acres of productive land throughout the arid and semiarid areas of the world. Slide 39 is a photograph of an area that has an excessive amount of salts. Since salts ionize when dissolved in water they can conduct electricity. The measure of conductivity, millimhos, is usually used for measuring the salts content of irrigation water.

Slide 40 indicates the tolerance of various crops for different levels of salt content in the soil solution. This tolerance also varies with the stage of growth of the crop.

Salinity in the soil solution will at least equal that in irrigation waters. Due to evaporation, soil solution concentrations in arid areas generally exceed those of applied waters. Criteria have been developed, as shown in Slide 41, for the evaluation of the salinity hazard of irrigation waters and are somewhat applicable for use when evaluating wastewaters

for irrigation. New criteria, based on soil type as well as plant tolerance and assuming ideal irrigation conditions, as might be found on a well designed and managed land application site have been developed and might be more applicable to a land treatment situation. These criteria indicated in Slide 42 are only for permeable soil with good drainage, either natural or artificial. When a significant fraction of the applied wastewater moves through the soil as percolation, salt buildup would not be a problem even in arid areas, under normal circumstances. The percolate, in this case, leaches the salts from the soil.

Certain salts are more of a problem than others for various reasons. Sodium is critical because it affects plant growth directly, and indirectly, through its undesirable effect on soil structure and permeability. Boron has been identified as a problem in some irrigated areas. As shown in Slide 43, crops vary in their relative tolerance to boron and to sodium.

Farmers generally grow the crops best adapted to their area. Slide 44 indicates a number of the considerations used in selecting a crop for a particular area. Crop selection for maximum growth and nutrient uptake at land application sites, where available moisture should be abundant will be limited primarily by yearly temperature fluctuations and solar energy.

Perennial crops have an advantage in that they can begin growth and develop a crop canopy as early in the year as temperatures permit. They do not have to wait for preparatory tillage operations. The early growth of a perennial often is rapid because they enter the growing season with considerable food reserves. Slide 45 summarizes the advantages of planting a perennial at a land application site.

Tropical grasses, such as bermuda grass, shown in Slide 46, have a greater capacity to stand heat and utilize intense radiation than do temperate species. Under these conditions tropical grasses have been established at land treatment sites and utilize maximal amounts of water and nutrients. Because they are sensitive to cold, however, they grow only during warm seasons and cannot even be successfully maintained further north than the Carolinas.

In the South, and parts of the West, the growth of cool season crops may allow plant wastewater renovation throughout the year; in the North periods exist when no crops will grow actively. Nevertheless, as shown in

Slide 47, crop selection can contribute to lengthening the season of active growth. Fall seeded small grains grow later in the fall and earlier in the spring than pasture and meadow crops. The Army Corps of Engineers grew a corn-rye cropping system combined with minimum tillage techniques. In this scheme rye was broadcast one to two weeks before corn harvest. The rye was harvested in mid-November and killed with a contact herbicide prior to no till corn planting in the spring. The nitrogen removal that occurred is shown in Slide 48.

In general, it is important that the land application site designer consult the local agricultural extension office, state college, or department of agriculture office for crop varieties and species suited to the area and the wastewater application situation (Slide 49).

There are two options in the farming of a land application site (Slide 50). The farm can be leased to a farmer who takes all of the risks but can potentially reap sizable profits or the farming can be managed by the system operators and the necessary labor hired. This latter course gives the waste treatment managers somewhat more control over the operation. An in house manager may find it easier to remember that a land application site is basically for the treatment of wastes and not primarily a profit making operation. The system operator's prime responsibility is to treat waste. A leasee's objective is to make a profit from the crop.

A land application site has the potential to provide a sizable return from the farming operations. As Slide 51 indicates, however, there are many operations that contribute to the successful production of a crop. All of the operations included in this slide must be completed at the proper time for the particular crop that is being grown. Slide 52 indicates 1977 production costs and expected returns from different farm crops. The figures in this table were compiled by considering the most productive soils receiving recommended management. Thus the yields are optimum. The figures also were compiled by considering that all of the tillage and harvest operations were done by custom operators. If unfavorable price conditions prevail at harvest, however, the situation would change drastically. If wheat brought only $1.50 a bushel then a yield of over 60 bu/ac would be needed to just break even. Also the value of silage and haylage is figured as feed value being fed to animals on the farm. These products are difficult to transport long distances and cannot be readily stored once removed

from a silo. It must also be remembered that application of water must stop several days before harvest in order to give the crop and the soil a chance to dry.

The selection of a crop and the correct management is part of the body of knowledge shared among farms throughout the country and agriculturalists at land grant institutions (Slides 53, 54, 55). It is essential that expert advise is obtained if a land treatment site is to also be a productive farming operation.

In summary, a vegetative cover is an essential part of a well designed irrigation or overland flow land treatment system. As these slides show, healthy crops contribute aesthetically to the site as well as providing a sink for constituents of the wastewater or sludge. A crop helps maintain soil structure which increases infiltration, percolation, and water holding capacity, and can provide a capital return for the system. It is necessary, however, to use solid fundamentals in the selection and management of an agricultural crop for a land application of wastes system (Slides 56, 57, 58).